Past President and Director of the Society
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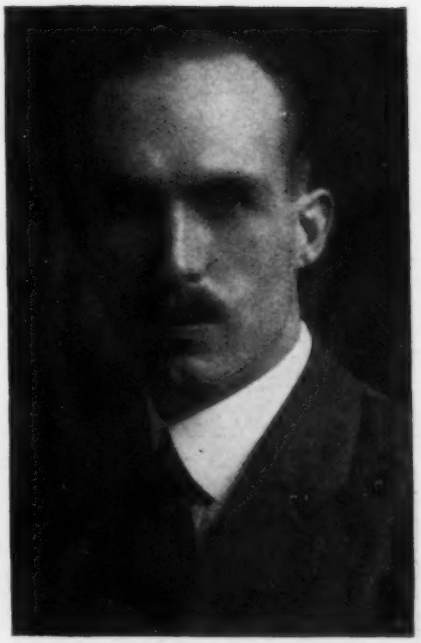

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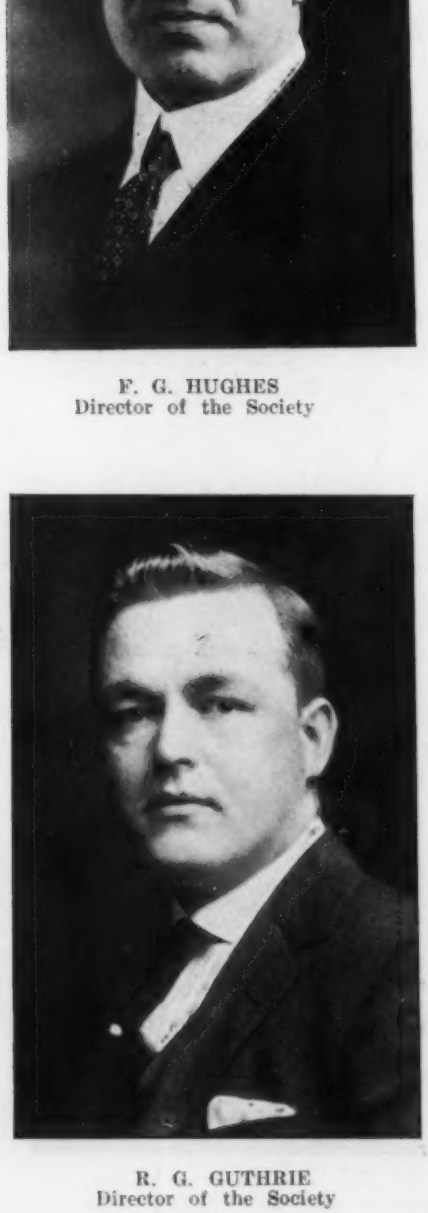
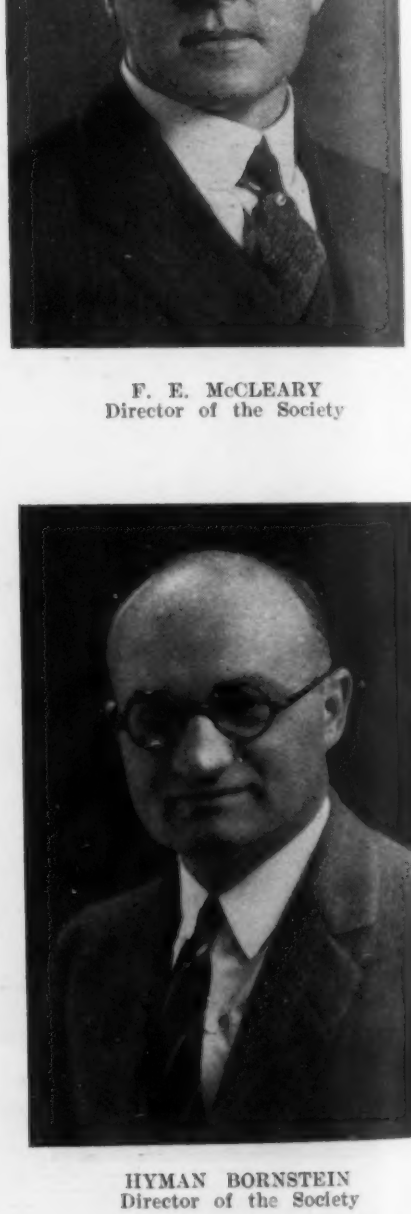


F. G. HUGHES
Director of the Society



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Director of the Society

R. G. GUTHRIE
Director of the Society

HYMAN BORNSTEIN
Director of the Society

WINTER SECTIONAL MEETING

ALL arrangements have been made for the Winter Sectional Meeting to be held in Buffalo, January 21 and 22, 1926, and the Buffalo chapter committees are to be complimented for their success.

An excellent program has been prepared, as is evidenced by the list of technical papers presented below, and this meeting gives

Niagara Falls as we hope it will appear January 23, 1926

every indication of surpassing previous sectional meetings. The Hotel Statler will be the headquarters.

Members will begin to gather on Wednesday, January 20, as on that day the newly elected national officers will hold the first meeting of the year at the Statler Hotel, for the transaction of important business. On the same date, the Publication Committee of TRANSACTIONS, under the direction of Professor H. M. Boylston, will hold a meeting at the Hotel Statler, for the consideration of publication problems and the determination of policy. Also the sub-committee on Tool Steel, under the chairmanship of W. J. Merten, will hold a meeting at the Hotel Statler on the same day. On Thursday morning, January 21, the technical sessions will begin. The activities of this sectional meeting are as follows:

PROGRAM FOR WINTER SECTIONAL MEETING, HOTEL STATLER, BUFFALO—JANUARY 21-22, 1926

WEDNESDAY, JANUARY 20

10:00 A. M.—Meeting of Board of Directors.
10:00 A. M.—Meeting of Publication Committee, H. M. Boylston, chairman.
10:00 A. M.—Meeting of Tool Steel Committee, W. J. Merten, chairman.
6:00 P. M.—Early Bird's Dinner and Theatre Party—Hotel Statler.

THURSDAY, JANUARY 21

Ball Room, Hotel Statler.

9:00 A. M. to 10:00 A. M.—Registration.

Morning Technical Session Dr. Zay Jeffries, chairman.

10:00-11:00 A. M.—The Laboratory as a Factor in the Inspection of Alloy and Tool Steels—W. H. Wills, Jr., metallurgist, Atlas Alloy Steel Corporation.

11:00-12:00 M. —Influence of Changes in Carbide Concentration on X-ray Structure of Some Pure Iron-Carbon Alloys—Dr. W. L. Fink, Aluminum Company of America.

Afternoon Session

1:30 P. M.—Plant Inspection.

Evening Session

6:30 P. M.—Informal Dinner, Ball Room, Hotel Statler.

FRIDAY, JANUARY 22

Ball Room, Hotel Statler

Morning Technical Session H. M. Boylston, chairman.

10:00-11:00 A. M.—A Report Supplementing the Work Relating to the Effect of Size and Shape on the Hardening of Steels—H. J. French and O. Z. Klopsch, Bureau of Standards, Washington.

11:00-12:00 M. —On the Nature of Alloys of Iron and Chromium—E. C. Bain, Union Carbide and Carbon Research Laboratories.

Afternoon Session

1:30 P. M —Plant Inspection.

Evening Session

Ball Room, Hotel Statler R. M. Bird, chairman.

7:30-8:30 P. M.—Electric Steel Melting from the Metallurgist's Viewpoint—Dr. Birger Egeberg, Halcomb Steel Company, Syracuse, N. Y.

8:30-9:30 P. M.—Macroscopic Examination of Iron and Steel—J. J. Curran, and F. P. Gilligan.
Henry Souther Engineering Company, Hartford, Conn.

SATURDAY, JANUARY 23

Trip to Niagara Falls.

H. J. FRENCH

F. P. GILLIGAN

W. L. FINK

E. C. BAIN

W. H. WILLS

O. Z KLOPSCH

J. J. CURRAN

BIRGER EGEBERG

AUTHORS OF PAPERS TO BE PRESENTED AT THE WINTER SECTIONAL MEETING BUFFALO, JANUARY 21 AND 22

NOTABLE CONTRIBUTIONS TO THE SCIENCE OF METALLURGY

THIS issue of TRANSACTIONS contains several especially valuable papers dealing with both theoretical and practical metallurgy. Two of these papers were presented before the Cleveland Convention of the Society last September, and at the time of their presentation created much favorable comment. A third paper will be presented before the Winter Sectional meeting of the Society to be held in Buffalo, N. Y., January 21 and 22, 1926.

The paper by Messrs. French and Klopsch, entitled "Initial Temperature and Mass Effects in Quenching," is a very important contribution to the science of heat treatment, and their work, which is still in progress, promises well to be of invaluable service to steel treaters. The results of quenching experiments with high carbon steels are given in which the speed of cooling was determined at the center of spheres, rounds and plates of various dimensions quenched from various temperatures, into different coolants, such as water, 5 per cent sodium hydroxide, oils and air. The cooling velocity at 1330 degrees Fahr. is taken as the best measure of hardening produced. Relations are also developed between the size and shape of the tool quenched.

The paper by Messrs. Gill and Frost, entitled "The Chemical Composition of Tool Steels," is of much interest and is a valuable discussion of chemical composition of tool steels and the effect of certain elements upon the physical properties of these materials. This is one of the most extensive discussions of the subject which has ever been presented.

A third paper by E. C. Bain, entitled "The Nature of the Alloys of Iron and Chromium," is published in this issue of TRANSACTIONS and will be presented and discussed at the sectional meeting to be held in Buffalo the latter part of this month. Mr. Bain has contributed many valuable papers before scientific societies, but it is felt that this contribution is the best that has been made by him. This paper describes the development and preservation at room temperature of delta iron solid solution This study no doubt will be far-reaching.

ANNUAL CONVENTION AND EXPOSITION—Municipal Pier, Chicago, Illinois, September 20-24, 1926.

THE NATURE OF THE ALLOYS OF IRON AND CHROMIUM

By E. C. Bain

Abstract

This paper describes for the first time, it is believed, the development and preservation at room temperature of Delta iron solid solution. The alloys are heated above the range for austenite formation and upon quenching in water the transformation to austenite is suppressed and the Delta iron solid solution is preserved unchanged in a permanently stable form identical with Alpha iron solid solution or ferrite. The name Delta iron signifies only that the material has been heated to a higher temperature than permits austenite to exist in contrast to Alpha iron—a material which has been transformed from austenite by cooling through the transformation temperature at a proper rate. Physically the two are identical.

Iron, in its Alpha form, accepts up to at least sixty per cent chromium in solid solution and probably forms a continuous solid solution series with it in all proportions.

The solid solutions of chromium in iron containing less than about fourteen per cent chromium exhibit the Alpha-Gamma and Gamma-Delta transformations upon heating. The temperature for the Alpha-Gamma transition is raised with increasing chromium content while the Gamma-Delta change takes place at a lower and lower temperature as the chromium proportion is increased. The temperature range for Gamma iron stability, therefore, becomes narrow above about ten per cent chromium, and Gamma iron is not formed at any temperature in the alloys having much more than fourteen per cent chromium except as influenced by carbon. In alloys richer in chromium, Alpha and Delta iron solid solutions are continuous and are physically identical. Delta iron solid solutions have been preserved, by quenching, permanently stable at room temperature.

The carbon which is usually present in any alloys of this type acts primarily to enlarge the region of austenite formation—raising the Gamma-Delta temperature and lowering the Alpha-Gamma temperature. Furthermore, carbon extends the region of Gamma iron for-

A paper to be presented before the Winter Sectional Meeting of the Society, Buffalo, N. Y., January 21-22, 1926. The author, E. C. Bain, member A. S. S. T., is metallurgist with the Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

mation into the richer chromium alloys. Carbon when present in as large amount as 0.35 per cent produces some Gamma iron even in alloys containing 30 per cent chromium.

Both chromium and carbon render austenite more sluggish and reluctant to transform into Alpha iron (martensite) upon cooling. About 12 per cent chromium is required to preserve any appreciable austenite at room temperature after a water-quench, even with the carbon as high as 0.35 per cent.

Earlier Work

IT is to be expected that iron and chromium would form a continuous solid solution series. If one reasons by the method of analogy, which admittedly is precarious in the field of metallography, he will find parallel examples in the case of molybdenum-tungsten and still more remotely in copper-gold and silver-gold. In these series, the metals, which are at the same time chemically similar and of the same atomic arrangement, form the continuous solid solution series. Some years ago the writer corroborated this opinion by examining a series of iron-chromium alloys by means of the X-rays. The specimens of various compositions, all rapidly cooled from near the melting point, showed only a single metallic phase, having the body-centered cubic arrangement of atoms found in both chromium and iron. The alloys for these examinations were, however, made by the process of sintering together the compressed fine powders of the two components. The sintering was accomplished at a temperature near the melting point and diffusion was believed to have taken place; but this method is always open to the criticism that homogenization may not be completed. To decrease the likelihood of imperfect diffusion the series of specimens was held at elevated temperatures for many hours and again examined by X-rays after slow cooling. The resulting crystallograms contained faint lines which were not part of the body-centered cubic pattern. This seemed at first to corroborate the view that with very long time at certain temperatures iron and chromium do form an inter-metallic compound. However, this evidence was obtained chiefly in those samples which contained iron and chromium in about the ratio of 1:7 or 7:1. Consequently, it seemed more likely that the extra spectogram lines were not contributed by a new constituent but by the regular arrangement of the two

kinds of atoms in the same space lattice. At any rate, the preponderance of evidence is in favor of the continuous solid solution conception, and it is the consensus of opinion of investigators who have studied the range of the present research.

The series of alloys examined by the X-rays in this study were made from pure hydrogen-reduced iron, and aluminum-reduced chromium. The only impurity present in significant proportion was silicon, and it is quite unlikely that it could be responsible for the development of any new phase.

Method of the Present Study

The present study primarily covers the range of alloys between pure iron and 30 per cent chromium. A few alloys containing as high as 60 per cent chromium were made for the purpose of checking the solid solution conception. None of the series is, in any sense, a pure alloy of iron and chromium. They are low-carbon iron-chromium alloys made from Armco iron and low-carbon ferrochromium. Any inferences which will be drawn subsequently as to the behavior of practically pure iron-chromium alloys will be explained in connection with the carbon effect.

About six pounds of comparatively sound metal were made for each composition studied. These were prepared by melting in a high-frequency induction furnace, and the ingots were forged to ½-inch square bars for metallographic examination after heat treatment.

To obtain the structure of the annealed alloys, forged bars were heated to about 1100 degrees Cent. (2000 degrees Fahr.) and cooled over a period of about two days. Such annealed bars were then cut into small cubic metallographic specimens and were given the various heat treatments described later. Groups of specimens containing one sample each from the various analyses were heated in a tungsten-wound furnace in hydrogen atmosphere and then quenched in cold water. The hydrogen caused some surface decarburization but prevented scaling. This collection of specimens of various compositions and a variety of heat treatments constituted the material for study. The chart of Fig. 1 shows the distribution of specimens in two series, one with a low carbon content (0.10 to 0.26 per cent carbon) and another with higher carbon content (0.26 to 0.50 per cent carbon).

The total number of specimens to be examined micro-

scopically was made as small as possible. Seven different quenching temperatures covered a 500 degree Cent. (900 degree Fahr.) temperature range. Consequently, with such necessarily large temperature intervals between quenches, the exact region of any given structural change, in point of temperature, may be entirely

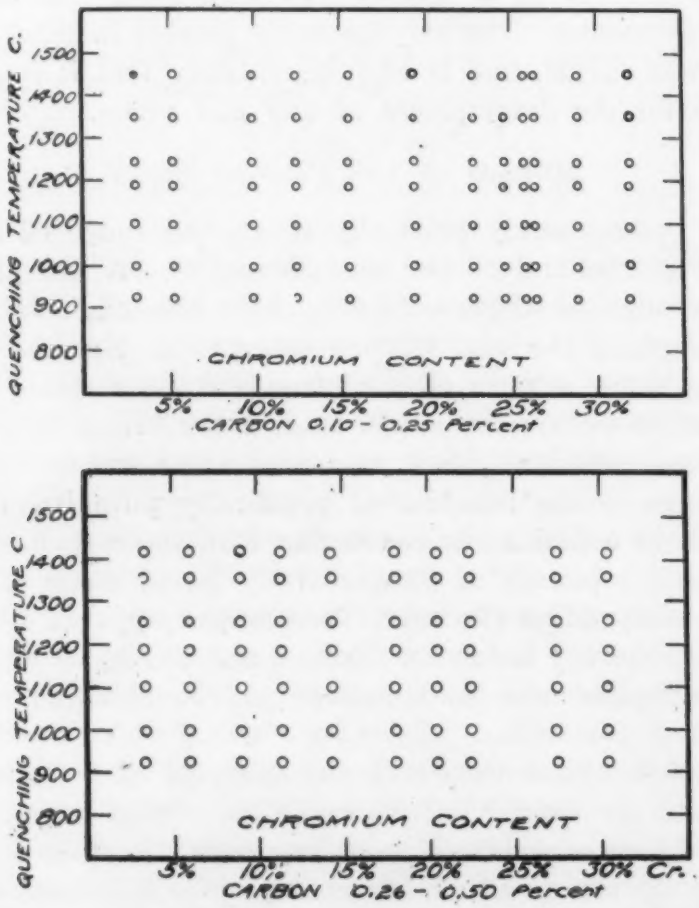

Fig. 1—Charts Showing Composition and Quenching Temperature of the Various Specimens Used in this Study.

missed. The mechanism of the structural change is often of as much interest as the transformation itself. In series of the sort described, it is regrettable that the exact mode of the change is so likely to be lost. To remedy this condition a somewhat different method of heat treatment was applied to a specimen from each analysis. A bar about 1¼ inches long was held from below in such a manner that its lower end was immersed in cold water to a depth of about ¼ inch. The other end was heated gradually with the oxyacetylene torch until the top was just

fused. This condition, with as uniform temperature gradient as possible, was maintained for a few minutes and then the specimen was suddenly quenched in cold water. The oxyacetylene flame was maintained as nearly neutral as experience makes possible. A longitudinal section of such a specimen, when carefully polished and etched, gives the continuous thermal history of the

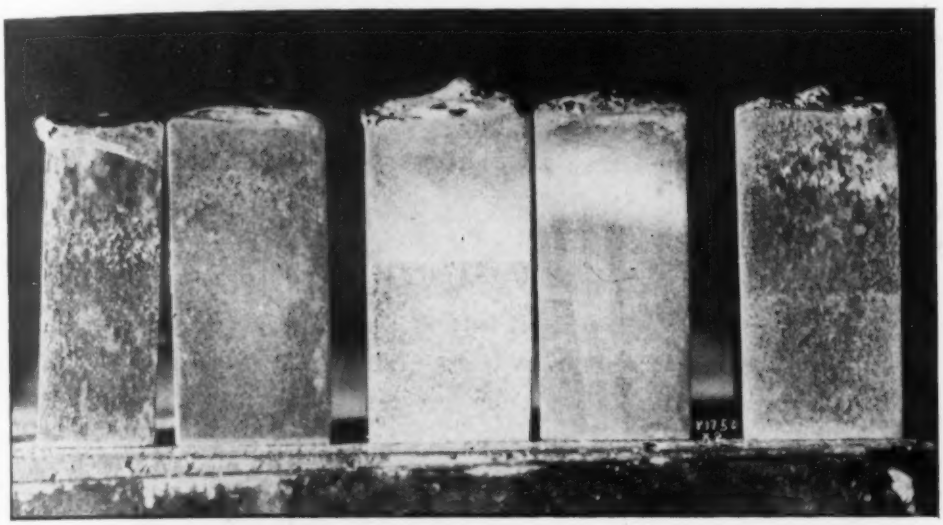

Fig. 2—Continuously Heat Treated Specimens Fused at Upper End by the Oxyacetylene Torch. The Lower End was Held Under Cold Water. Note Zones of Structural Change. Magnification 2X.

alloy between the melting point and room temperature. In general, the alloy was not held at any specific temperature along this length for more than five or six minutes. This period admittedly is too short to bring about perfect equilibrium conditions, but it is not too inadequate for an accurate interpretation of the structural changes as they are produced by the heat treatment. Obviously, even approximate estimation of temperature corresponding to a region of structural change cannot be made, but calibrating such a continuously heat treated specimen against the specific specimens as above described, limits the temperature range for any particular phenomenon quite satisfactorily. Fig. 2 shows a few of these torch-heated specimens at 2 diameters magnification after polishing and etching.

The present study of the alloys of iron and chromium was made principally by the use of the microscope. The microscope was supplemented by hardness measurements and by the X-ray crystallometer on some few specimens whose microstructure could

not be interpreted without ambiguity. In the charts of Figs. 3 and 4 are shown reduced photomicrographs of all the specimens in the two series—low and medium carbon. The small sections of photomicrographs are placed upon the chart in a manner to indicate by their location approximately the heat treatment and composition of the alloy. Arranging the prints in this manner enables one to contemplate the entire series with the heat treatment and composition constantly in mind. The prints in several cases, however, have been trimmed to a size rather too small. All photomicrographs in the reduced charts were made originally at 100 diameters and the plots were very convenient for study.

Iron-chromium alloys are rather difficult to polish. The metal is unusually deeply disturbed by the coarser abrasives and usually requires several polishes with alumina, or its equivalent, following a rather severe etch each time. Gradually the effects of the coarser scratches are eliminated. Most of the etching reagents either etch too slowly or develop severe pitting. The reagent finally employed was aqua-regia in glycerine as adapted by J. R. Vilella. It does not stain and seems about equally effective and rapid on the various proportions of chromium. Austenite is only slowly attacked and, therefore, may be identified by its brilliant whiteness in contrast to the ferrite, martensite, or *delta* iron, with which it is associated.

The continuously heat treated specimens prepared, as described above, by the use of the oxyacetylene torch were photographed over their entire significant length. Successive photographs were matched and trimmed so that without the omission of a single grain in the material the entire thermal history may be read from one end of the strip to the other. At 100 diameters magnification the strips vary in length from 3 to 4 feet, and are not suitable for reproduction in this paper.

At the outset it should be understood that the present study was conducted in order to give the general trend of the structural changes in the iron-chromium alloys, and accurate figures for the temperature of the various transitions are not within the scope of this paper, nor are the exact boundaries of the various structural regions of the diagram known with certainty. On the contrary, only the general shape of the areas was discovered. It is probable, however, that this first approximation of the structural diagram offered herewith may be regarded as accurate in the main to

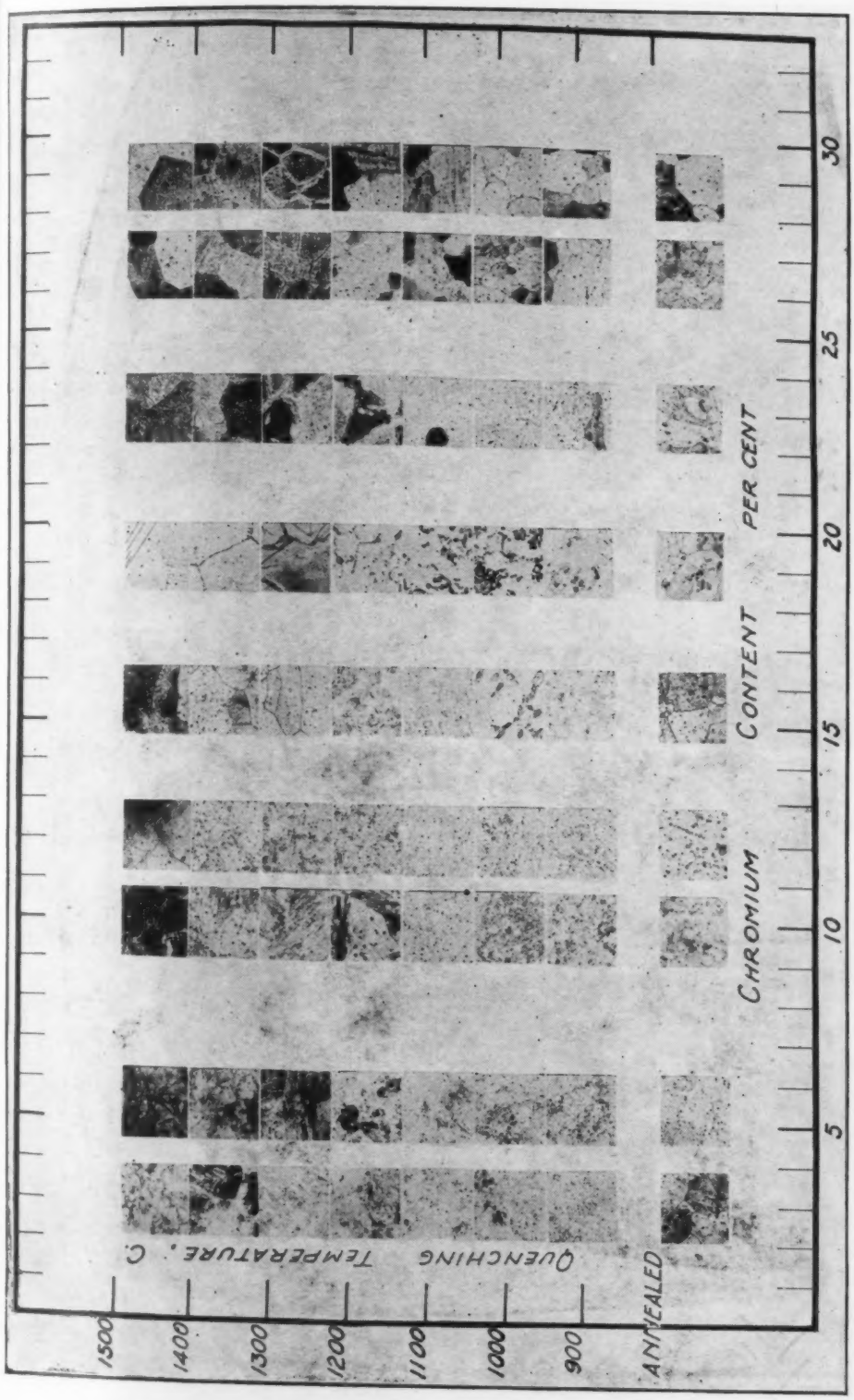

Fig. 3—Reduced Photograph of the Chart for the Low Carbon Alloys. Originals at 100 Diameters. Reduced to About ¼ Original Size.

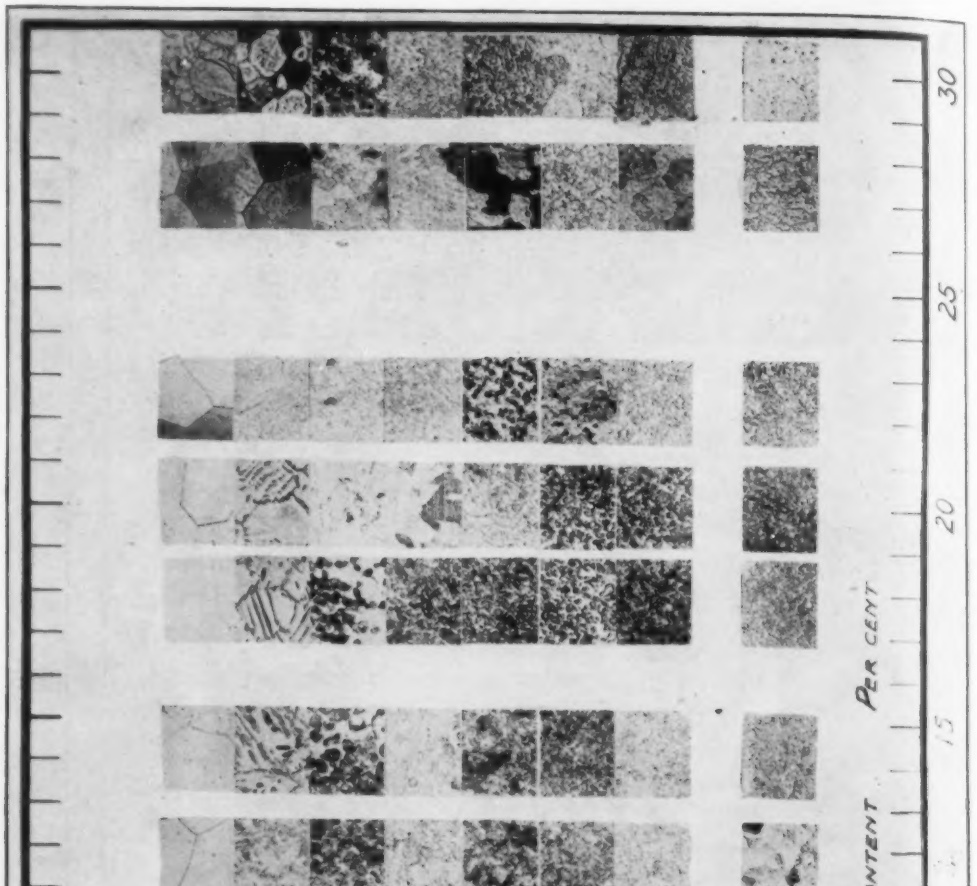

Fig. 4—Reduced Photograph of the Chart for Medium Carbon Alloys. Originals at 100 Diameters. Reduced to About ¼ Original Size.

Fig. 5—The Pearlite of an Annealed 9 Per Cent Chromium Alloy. The Carbon Content was Only 0.12 Per Cent. 500X.

perhaps 50 degrees Cent. (90 degrees Fahr.). This first approximation is adequate for a conception of the general nature of the iron-chromium alloys.

Results

The annealed low-carbon iron-chromium alloys are roughly analogous to the carbon steels but differ in a few characteristic details. In some of the alloys, pearlite is formed with a certain slow rate of cooling through the critical range but it lacks the regularity of carbon-steel pearlite. Further the estimation of carbon from the extent of the pearlite areas is quite uncertain. In general, the carbon content is actually lower than the pearlite area would indicate, in spite of the fact that the ferrite may hold more carbon in solution when considerable chromium is present. Pearlite was not observed in alloys containing more than 10 per cent chromium, the carbide particles being spheroidized. There was usually incipient spheroidization evident in the specimens which showed pearlite. Fig. 5 is a photomicrograph at 500 diameters of a pearlitic iron-chromium alloy containing only 0.12 per cent carbon.

For convenience, the behavior of the alloys will be presented by groups, the members of which have certain arbitrarily chosen properties in common.

GROUP 1—*Chromium Content Between 3 and 14 Per Cent*

With carbon present not in excess of 0.15 per cent the iron-chromium alloys containing up to about 14 per cent chromium behave very similarly indeed to the low carbon steels. Such alloys when heated to about 800 degrees Cent. (1570 degrees Fahr.) begin to become austenitic, and if quenched, yield martensite. At any rate, they are wholly martensitic if quenched from a temperature of above about 900 degrees Cent., and so far as can be determined they are also martensitic when quenched from as high a temperature as 1350 degrees Cent. (2460 degrees Fahr.). In this group, the alloys containing less than about 11 per cent chromium appear martensitic even when quenched from 1420 degrees Cent. (2590 degrees Fahr.). It is quite possible, however, that these alloys were not austenitic when quenched, but that they were in the form of *delta* iron solid solution which, however, was not preserved by the quench but transformed to austenite and subsequently to martensite. With about 12 per cent chromium and carbon up to 0.35 per cent a quench from 1420 degrees Cent. (2590 degrees Fahr.) yields a homogeneous polyhedral structure stable at room temperature and fully magnetic-*delta* iron. The proof of the identity of this constituent will be discussed below. In the alloys containing about 12 to 14 per cent chromium, a small amount of austenite is occasionally preserved at room temperature by quenching, if the carbon is as high as 0.35 per cent. In a word, then, this group is dominantly martensitic after a water-qnench and contains, at its upper limit, the lowest chromium content which succeeds in retaining *delta* iron unchanged at room temperature. With only 0.10 per cent carbon and 3 per cent chromium probably grain refinement alone results from the quench, but the acicular appearance, suggestive of martensite, may be observed.

GROUP 2—*Chromium Content Between 14 and 25 Per Cent*

With low carbon (below 0.25 per cent) this group of alloys is characterized by containing some microscopic areas of *alpha* iron absolutely unchanged, while the alloy is heated through the usual critical range up to 1420 degrees Cent. (2590

degrees Fahr.). Through this range of alloys there is a noticeable rise in the lowest temperature at which austenite is formed, and the temperature at which the alloy becomes wholly *delta* iron is greatly lowered. In fact, the only regions which undergo transformation are those fortuitously rich in carbon by virtue of being in the vicinity of carbide particles.

In the members of this group which contain more than about 20 per cent chromium the austenite is so sluggish as to be preserved as such at room temperature after the quench. When specimens of this group are heated to and quenched from a temperature which converts the alloy back to the body-centered cubic form of crystal (*delta* iron), one frequently finds the traces of old grain boundaries of austenite clearly showing as a secondary grain system entirely unrelated to the *delta* iron grain boundaries.

It is in this group of alloys that the effect of carbon is most marked. If the carbon content of such alloys is as high as 0.40 per cent the behavior of the alloys is quite different from that just described. In the first place, martensite is observed in the specimens quenched from temperatures as low as 950 degrees Cent. (1740 degrees Fahr.) to 1000 degrees Cent. (1830 degrees Fahr.). Furthermore, much more austenite is retained after the quench at room temperature and, lastly, the temperature for the production of pure *delta* iron is considerably higher. Only between 1350 degrees Cent. (2460 degrees Fahr.) and 1400 degrees Cent. (2550 degrees Fahr.) are the last traces of austenite destroyed to form homogeneous grains of *delta* iron. It is interesting to observe that a specimen containing 20 per cent chromium and 0.50 per cent carbon may be quenched from 1185 degrees Cent. (2170 degrees Fahr.) to produce a wholly austenitic alloy. When quenched from much below this temperature free carbide particles are still to be found in a martensitic matrix, and when quenched above this temperature the incipient development of *delta* iron is discernible in characteristic form. This same alloy when quenched from above 1400° C. consists of pure *delta* iron.

Group 3—*Chromium Content Between 25 and 35 Per Cent*

This group is characterized by being dominantly without transformation. The major portion of the alloy, even with carbon up to 0.35 per cent, remains unchanged throughout the entire temperature range between room temperature and the melting

point. Only occasionally in the vicinity of a large carbide particle of the annealed structure a small lake of austenite is produced at about 1200 degrees Cent. (2190 degrees Fahr.), which, at higher temperature, disappears. It is characteristic of this group that frequently carbide particles may resist solution in the solid up to temperatures in the vicinity of 1200 degrees Cent. (2190 degrees Fahr.) and then dissolve in *delta* iron solution with further elevation of temperature. In alloys containing less than 0.25 per cent carbon it frequently occurs that no austenite can be found at all in the specimens regardless of quenching temperature. Such alloys are truly without any trace of transformation and exhibit only the phenomenon of grain growth at about 1200 degrees Cent. (2190 degrees Fahr.). In these high chromium alloys one occasionally observes that a thin envelope, probably austenite rich in carbon, is developed about the *delta-alpha* grains at about 1200 degrees Cent. (2190 degrees Fahr.) and that subsequently the carbide is reprecipitated, after diffusion, more or less uniformly throughout the grains of *delta* iron. This fine precipitation of carbide usually disappears entirely in specimens heated to 1400 degrees Cent. (2550 degrees Fahr.) prior to quenching.

It remained for Westgren[1] to show conclusively that the discontinuity of magnetic and other properties in iron, just below the melting point, at about 1440 degrees Cent. (2625 degrees Fahr.) was accompanied by an atomic rearrangement. He found that upon heating through this temperature iron reverted to the crystalline form of *alpha* iron. This was in excellent accord with the results of earlier explorations into the realm of *delta* iron.

Carbon has been considered to obliterate this phase when present to the extent of a few tenths of a per cent. The author had for a long time considered the possibility of rendering *delta* iron sufficiently sluggish in transformation to permit its retention and study at room temperature by the addition of some element in solid solution. It appears that chromium contributes just such persistence. It was to be expected that such conditions would develop when it was discovered that chromium raised the austenite formation temperature and reduced atomic mobility so effectively.

The proof of the identity of the material lies in the facts that no recrystallization takes place during the quench and that

[1]Westgren and Phragman, *Journal*, Iron and Steel Institute, page 159, vol. 59, 1924.

the resultant material is fully magnetic and shows no twinning. Further, reheating such specimens to 700 degrees Cent. or just below the critical temperature causes on change except occasionally the precipitation of some carbides. See Fig. 6.

The foregoing description of the thermal behavior of the

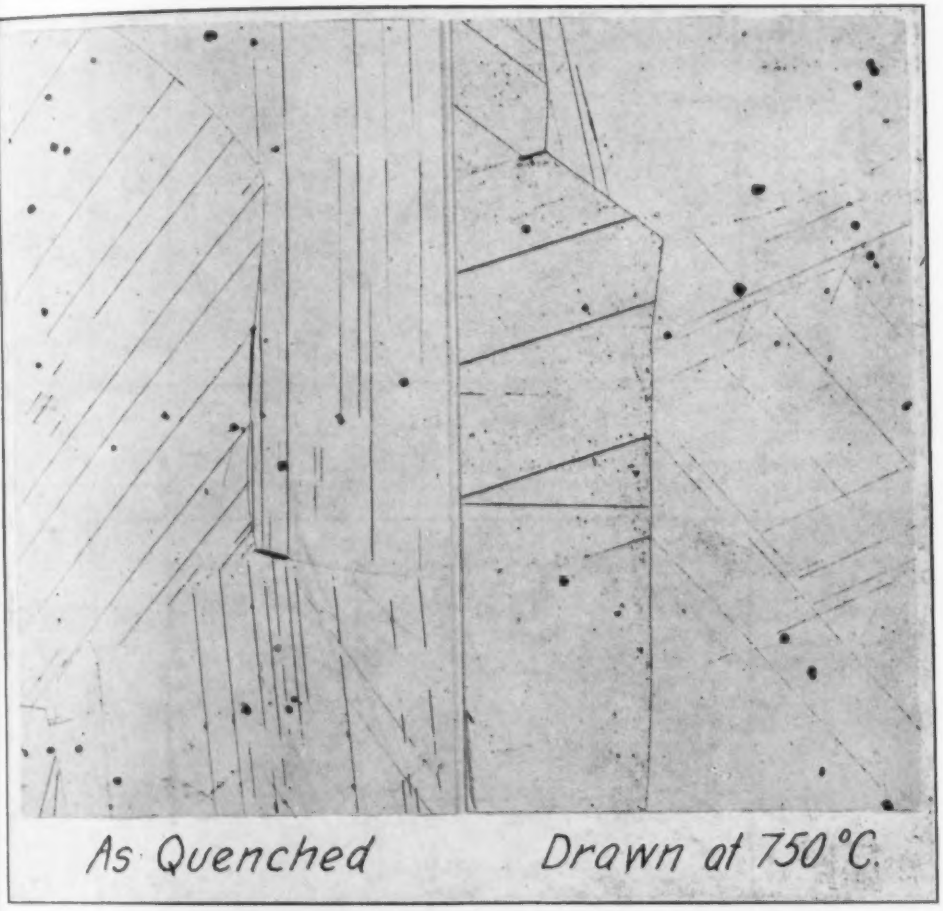

Fig. 6—Two Photomicrographs at 100 Diameters Magnification of Delta Iron Solid Solution Showing the Stability of the Phase. Heating to 759 Degrees Cent. (1320 Degrees Fahr.) for an Hour Causes no Change in the Alloys. Note Neumann Bands Caused by Hammer Blow.

various iron-chromium alloys is supplemented by a number of charts which show in a diagrammatic form the approximate temperature of the development of various constituents as affected by chromium content. These diagrams are self-explanatory and are drawn to indicate both the state of the material at elevated temperature and also the constituents which will be found at room temperature in the alloys after quenching in water. The boundaries of certain structural zones are shown in shaded areas,

since in this first preliminary investigation it was impossible to define the various structural regions with great accuracy. See Figs. 7 to 10 inclusive.

In the charts of Figs. 7 and 8 an attempt has been made to

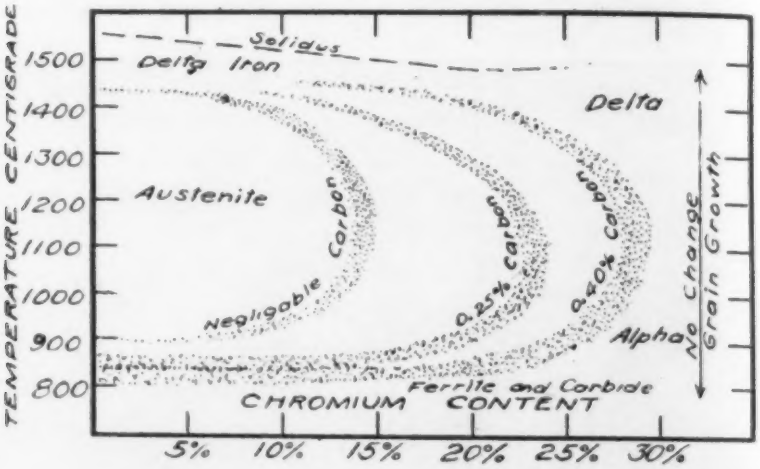

Fig. 7—Diagram of the Austenite Region in Iron-Chromium Alloys at Various Temperatures. The Diagram Shows Approximately the Effect of Carbon in Extending the Austenite Region Into the Richer Chromium Alloys.

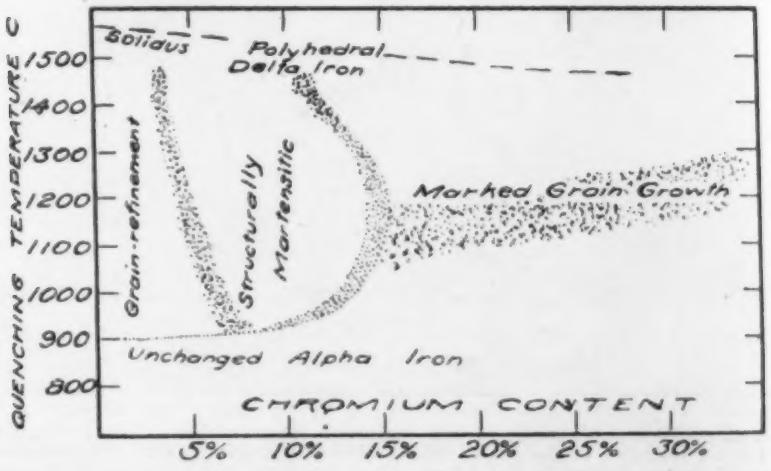

Fig. 8—Diagram Showing the Effect of Quenching Iron-Chromium Alloys with Negligible Carbon Content from Various Temperatures. The Areas are Marked to Indicate the Structure at Room Temperature After the Quench.

outline the behavior of alloys containing negligible carbon. By "negligible carbon" is meant such quantity as can be retained in solid solution in ferrite at room temperature after annealing. This amount may be as great as 0.20 per cent in the higher chromium alloys. Such alloys were rarely observed but it is believed that their behavior may accurately be inferred. Such assumption

is based on the behavior of the carbide particles themselves. Diffusion in the alloys of iron and chromium is notoriously sluggish; therefore, when an alloy is heated for a short time at a temperature for transformation the allotropic change takes place

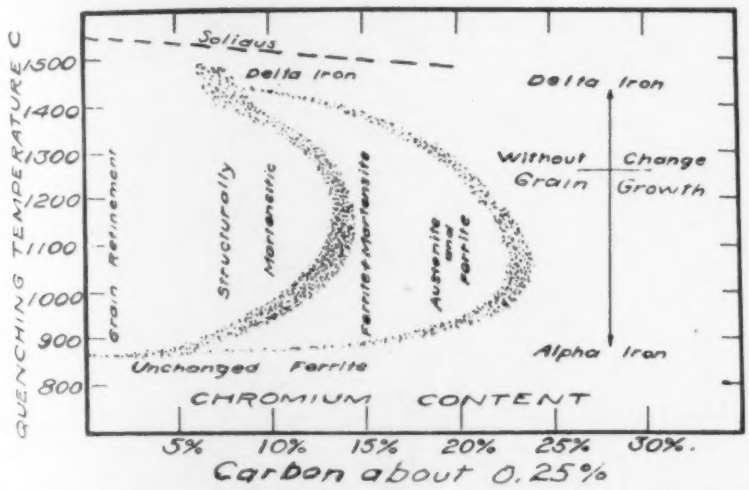

Fig. 9—Diagram Showing the Effect of Quenching Iron-Chromium Alloys with About 0.25 Per Cent Carbon from Various Temperatures. The Areas are Marked to Indicate the Structure at Room Temperature After the Quench.

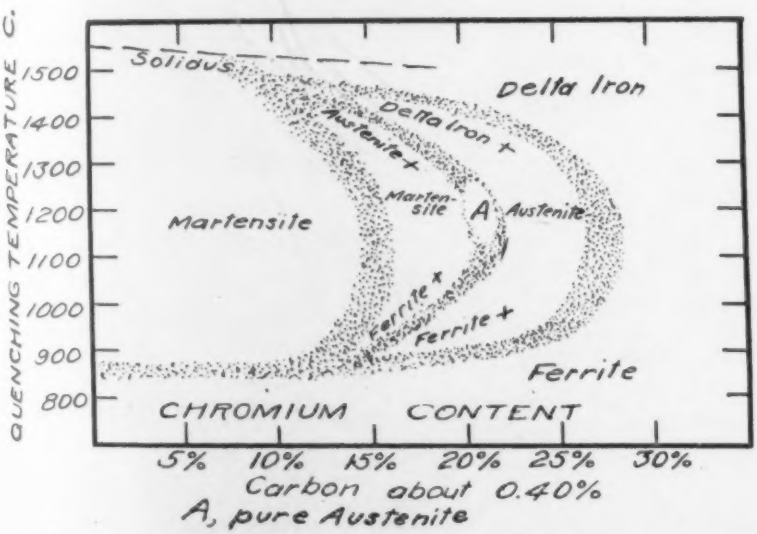

Fig. 10—Diagram Showing the Effect of Quenching Iron-Chromium Alloys with About 0.40 Per Cent Carbon from Various Temperatures. The Areas are Marked to Indicate the Structure at Room Temperature After the Quench.

far in advance of the solution of the carbide particles made possible by such allotropic change. To some extent, therefore, the excess carbon is inert (except at the highest temperatures) and the alloy behaves in the main much as though the carbon were

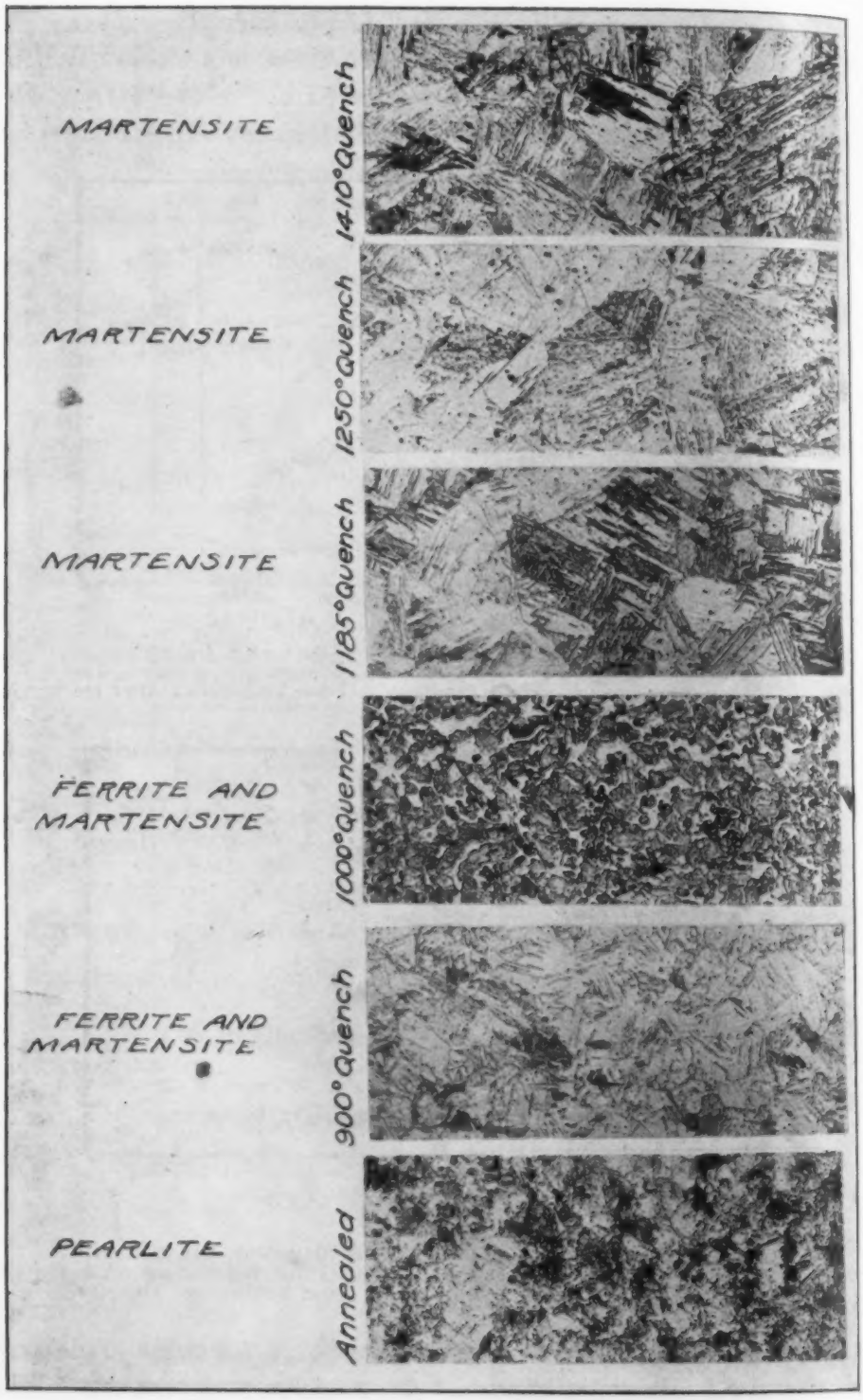

Fig. 11—Structures Obtained After Various Heat Treatments in an Alloy of 6 Per Cent Chromium and 0.30 Per Cent Carbon.

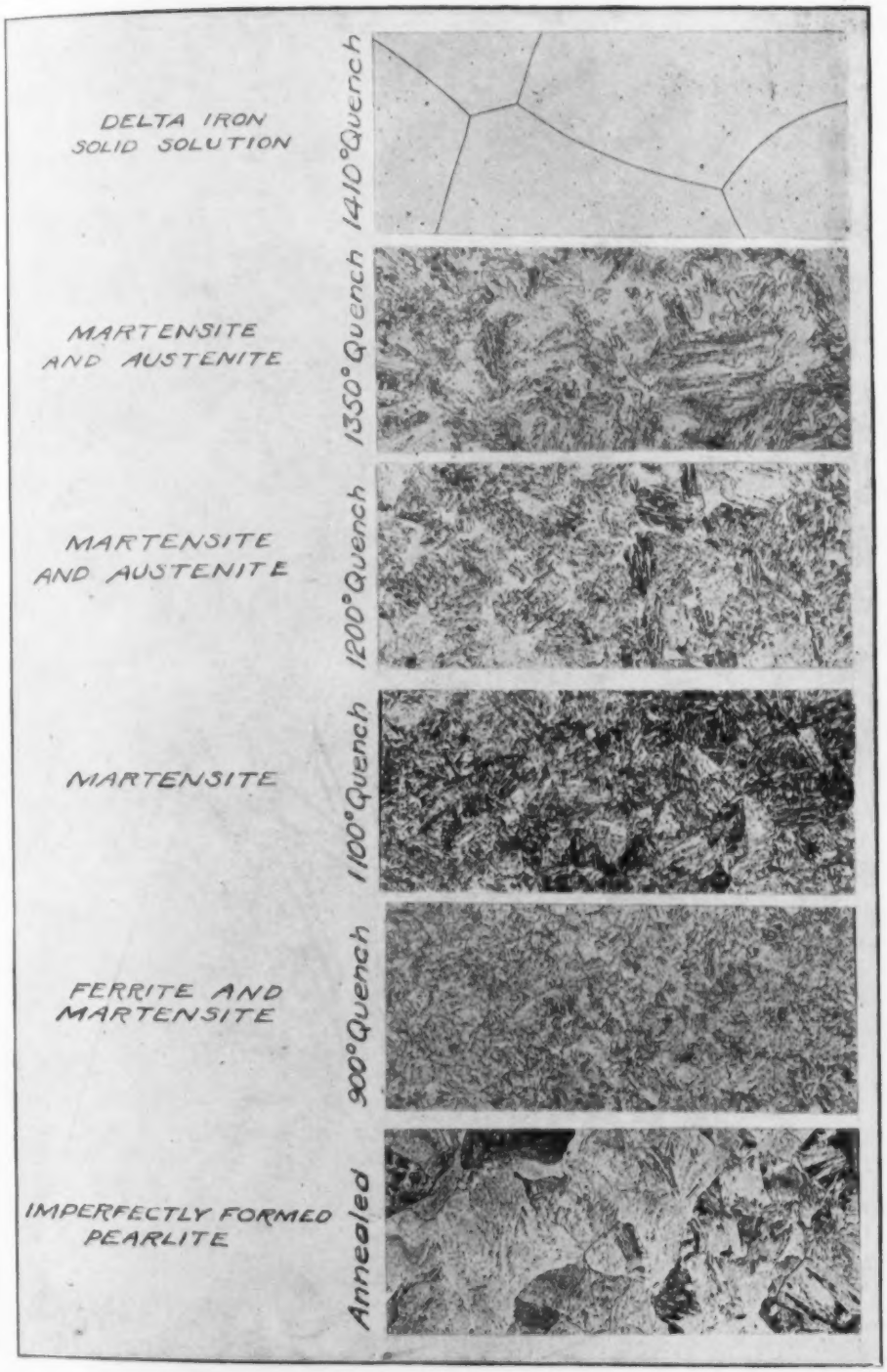

Fig. 12—Structures Obtained After Various Heat Treatments in an Alloy of 12 Per Cent Chromium and 0.25 Per Cent Carbon.

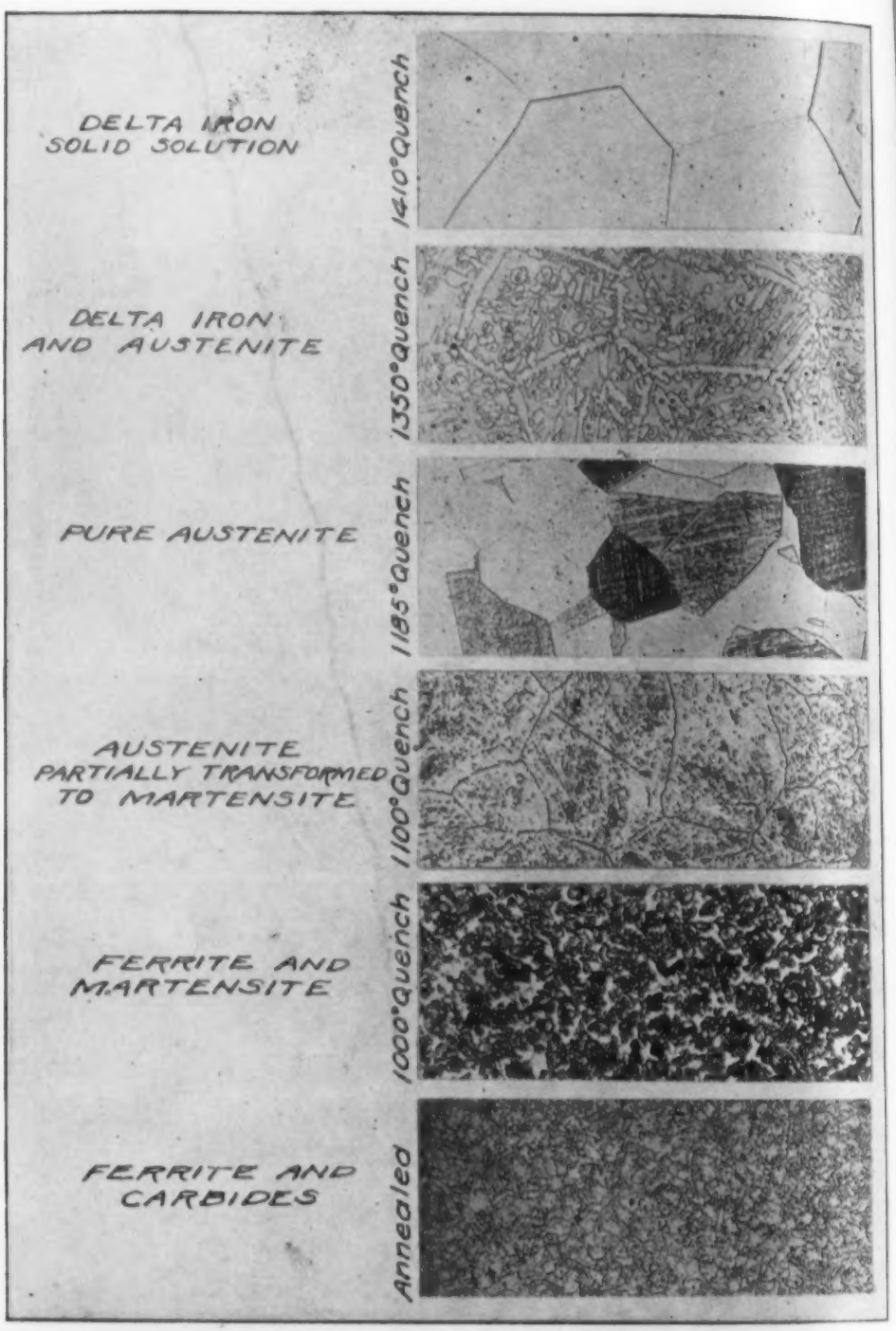

Fig. 13—Structures Obtained After Various Heat Treatments in an Alloy of 20 Per Cent Chromium and 0.50 Per Cent Carbon.

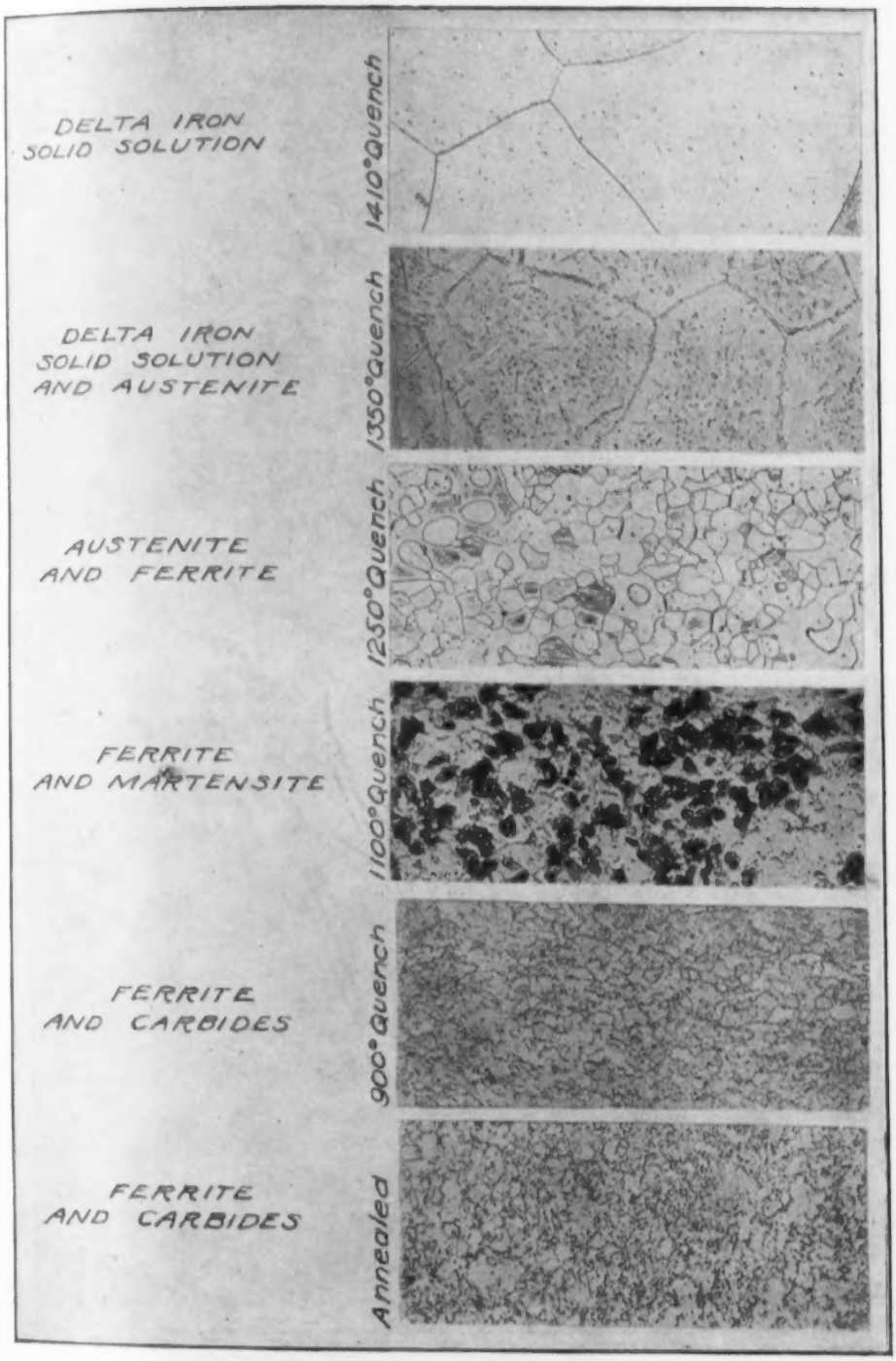

Fig. 14—Structures Obtained After Various Heat Treatments in an Alloy of 22.5 Per Cent Chromium and 0.40 Per Cent Carbon.

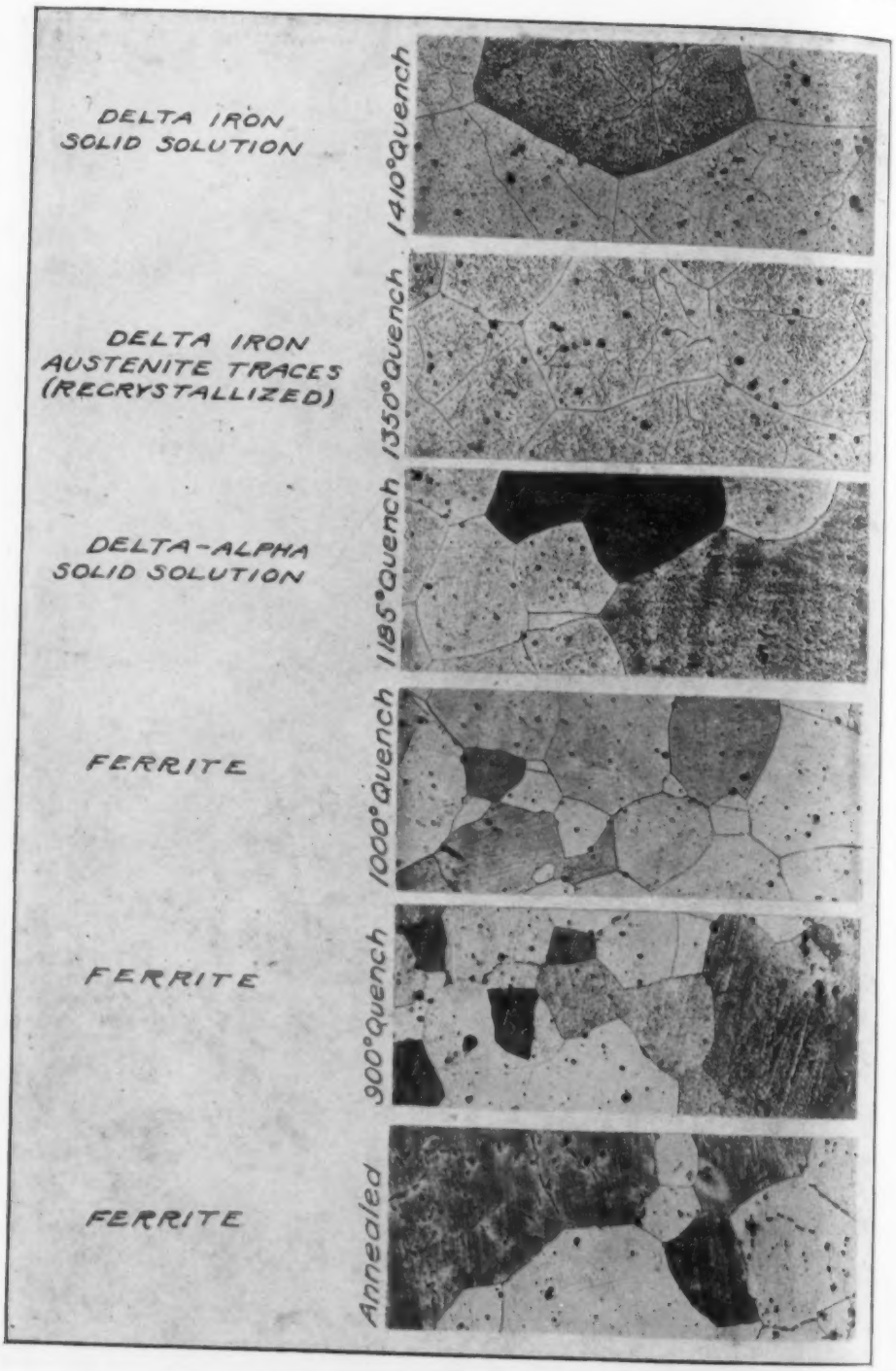

Fig. 15—Structures Obtained After Various Heat Treatments in an Alloy of 28 Per Cent Chromium and 0.25 Per Cent Carbon.

not present. Furthermore, by studying the trend of the carbon effect in higher carbon alloys the general nature of its influence in any particular alloy can be inferred. As example, when we find that certain grains of the original *alpha* iron remain more or less intact during the entire thermal history of a 15 per cent chromium alloy during heat treatment, the inference may be correctly drawn that without carbon no austenite would be formed, since the regions of martensite gradually increase in extent up to about 1100 degrees Cent. and then rapidly disappear, leaving pure *delta* iron, after higher temperature treatment.

One of the most surprising observations made during this study was that of the high solubility of carbon in *delta* iron at high temperature [in excess of 1400 degrees Cent. (2550 degrees Fahr.)]. It is scarcely to be considered that at such a temperature any phase could long remain supersaturated, and yet in an alloy of 20 per cent chromium polyhedral grains of *delta* iron solid solution have been preserved at room temperature without a trace of carbide precipitation when the alloy contained 0.50 per cent carbon. Upon reheating such grains of *delta* iron at 750 degrees Cent. (1380 degrees Fahr.) the excess carbide is precipitated within the grains.

The diagram of Fig. 16 is a three-dimensional chart having for elevation the approximate hardness (Rockwell C) of the entire high carbon series. The base of this three-dimensional chart has for ordinate, quenching temperature, and for abscissa chromium content. The region of the alloys which undergo transformation into *gamma* iron is clearly separated from the region essentially free from allotropic change. The reversion in high temperatures to the *delta* or body-centered cubic modification is also clearly shown for these alloys in which the chromium has depressed the *gamma-delta* change into the present range of heat treatment. Two or three anomalous hardness measurements were not plotted on this diagram in the interest of clarity, with the result that a smooth surface has been developed. The alteration, however, amounts only to a few points in Rockwell C hardness. The erratic value for these single points is explained by the vagaries of the quench in respect to the preservation of the soft austenite which is so delicately balanced against the development of martensite.

The austenite preserved at room temperature from these low-carbon iron-chromium alloys requires a rather unexpectedly high

temperature for decomposition. The series of photomicrographs in Fig. 17 shows the gradual change to *alpha* iron with increase of drawing temperature. This change brought about by tempering increases the hardness markedly in a uniform manner. This austenite, however, is not resistant to cold work to the extent

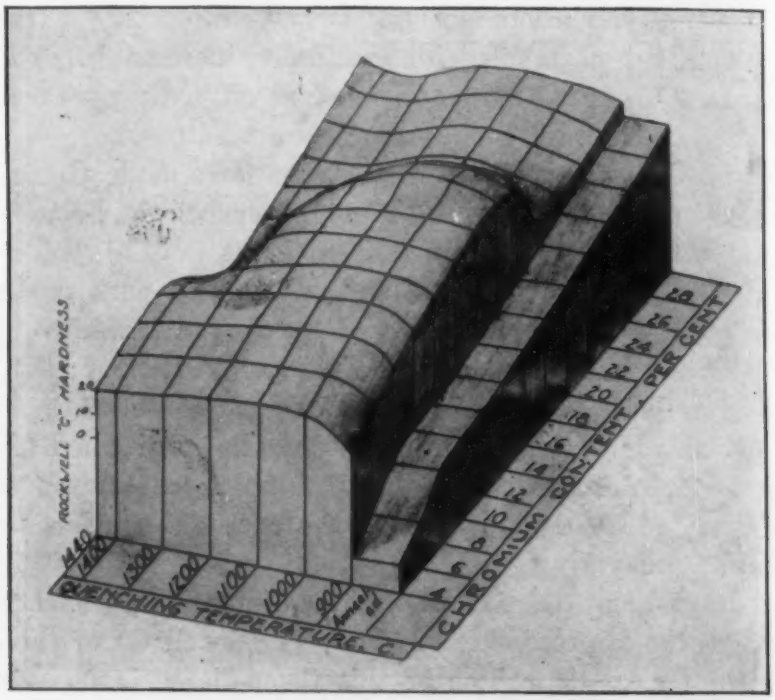

Fig. 16—Chart Showing (in Elevation) the Hardness Trends in Various Iron-Chromium Alloys After Quenching from Various Heat Treatments. At the Right is Shown the Hardness of the Annealed Alloys.

that might be expected. Great care was necessary in the polishing of the austenitic specimens to prevent the development of transformed material as a result of the scratching of the first coarse abrasive. The method finally adopted for polishing austenitic specimens was to etch away transformed material by an unusually vigorous treatment and redevelop the polish with alumina.

Wherever the microscopic appearance was ambiguous, recourse was had to X-ray examination as the final criterion. Fig. 18 shows two X-ray crystallograms side by side. The upper one is of a practically pure austenitic specimen and the lower one is the crystallogram of the same material after considerable cold work under the hammer, the unmodified material is obviously coarse grained, as shown by the dashed appearance of the face-centered cubic pattern. The lower crytallogram is obviously of

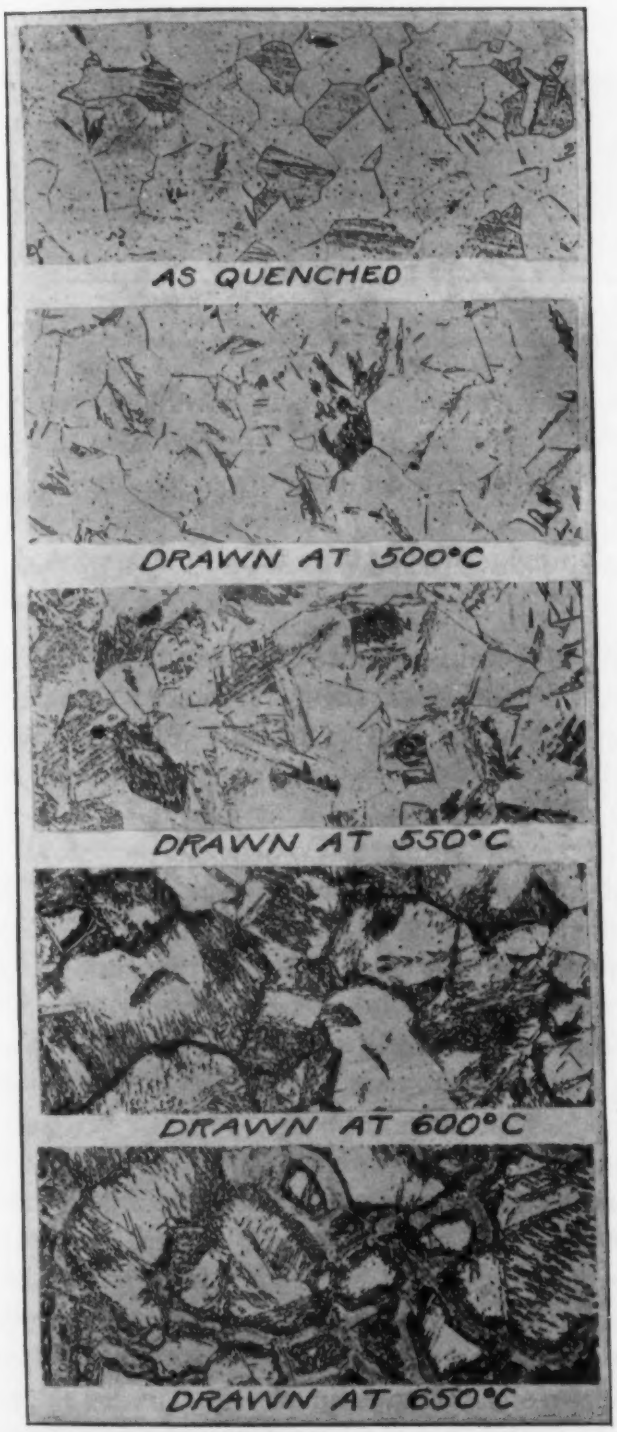

Fig. 17—Photomicrographs at 100 Diameters of the 20 Per Cent Chromium Austenite as it is Decomposed by Successive Heatings to Various Temperatures. Note Appearance in the Specimen Drawn at 650 Degrees Cent. of a Material with the Structure of Troostite.

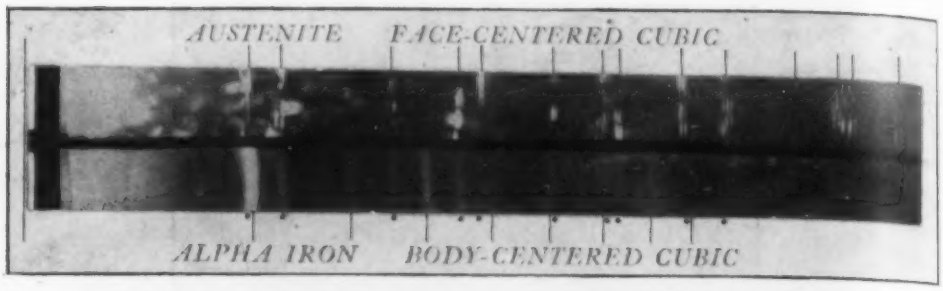

Fig. 18—X-Ray Crystallograms. Above, a Pattern of Coarse-Grained Austenite. Below, the Same Material After Severe Cold Work. The Austenite has been Fragmented and Alpha Iron Developed—a Proof of the Identity of Austenite.

a mixture of about equal parts of austenite (now fine grained) and body-centered cubic material—ferrite, also fine grained. This simple test constitutes a complete proof of the identity of austenite. Such a test was usually unnecessary, since prolonged etching would develop evidence of twins visible under the microscope.

Summary of Results

1. Alloys containing more than about 25 per cent chromium are without transformation, *alpha* iron and *delta* iron solid solutions being continuous and identical. With this chromium content carbon in excess of 0.40 per cent is required to produce an appreciable amount of austenite at any temperature.

2. In iron-chromium alloys containing more than 10 per cent chromium, *delta* iron is produced in a form sufficiently stable to be quenched unchanged to room temperature. It is formed at a decreasing temperature with increase in chromium content. At room temperature it is then ordinary ferrite and permanently stable.

3. In the absence of appreciable carbon, chromium will not dissolve in *gamma* iron in excess of about 14 per cent. That is to say, *gamma* iron is not produced in alloys containing more than this amount of chromium.

4. Carbon acts to increase the solubility of chromium in *gamma* iron and to render it a stable constituent in alloys containing more than about 14 per cent chromium. The iron-chromium alloys containing less than about 10 per cent chromium behave similarly to low-carbon steel producing a material upon quenching which is structurally martensitic with rather lower carbon content than would be found in a steel yielding the same structure.

The author gratefully acknowledges the assistance of his associates, H. S. George, W. E. Griffiths and J. R. Vilella, all of whom offered valuable suggestions for the work. Mr. George contributed many charts; Mr. Griffiths prepared most of the alloys and directed their heat treatment; Mr. Vilella devised the technique for developing structures shown in the photomicrographs.

INITIAL TEMPERATURE AND MASS EFFECTS IN QUENCHING

By H. J. French and O. Z. Klopsch

Prefatory Abstract

In this report are given results of quenching experiments with high-carbon steels in which the speed of cooling was determined at the center of spheres, rounds and plates of various dimensions quenched from various temperatures into different coolants such as water, 5 per cent NaOH, oils and air. The cooling velocity at 1330 degrees Fahr. (720 degrees Cent.) is taken as the best measure of hardening produced, and relations are developed between this and the size and shape of steel quenched. Knowing the described cooling rate at the center of any one size of the simple shapes quenched in any of the customary quenching media, such as oils and aqueous solutions, the velocity in any other size in such shapes can be closely approximated from the included data when the steel is quenched from any temperature between 1330 and 1920 degrees Fahr. (720 and 1050 degrees Cent.). Typical examples are given.

I. Introduction

DURING the past twenty or thirty years a great deal of attention has been given to the properties produced in carbon and special steels by quenching and tempering and to the constitutional changes brought about by different heat treatments. Helpful diagrams have been prepared which not only promote a better understanding of the changes taking place, but also permit surprisingly accurate predictions of the properties which will result from different heat treatments.

It is, for example, now generally well known that the properties of a given steel depend primarily upon the temperature from which it is cooled and the manner of cooling and that this latter variable is dependent upon the coolant which is used and the size and shape of the steel under treatment. While the effects

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of varying mass upon the resulting properties have been studied, little attention has been given to the changes in cooling rates except in a very general way. More nearly quantitative information in this respect would be helpful in the selection of correct heat treatments as well as in comparisons of quenching media and with this in view the experiments described in this report were carried out.

For results which would be most generally useful a study should be made of the temperature distribution as well as the cooling at the center of different sizes and shapes of steel. The described experiments are, however, restricted to the latter phase and will form a basis of comparison for additional work which it is hoped will be undertaken at a later date.

II. Previous Investigations

It is possible to gain a general idea of the effects of size and shape on the cooling of steels from the theory of heat conduction first perfected and applied by Fourier,[1] but while some results are obtained which appear consistent with actual experience or tests, they cannot be considered quantitative, they necessitate elaborate and tedious calculations and require various assumptions which introduce an element of doubt upon the validity of many of the conclusions which are drawn.

Comparisons by Heindlhofer[2] of a mathematical study of the temperature changes in a hot body after quenching, and experimental cooling curves of metal cylinders quenched in water, developed a number of discrepancies with the several theories on rapid cooling. The principal feature of interest in connection with the experiments to be described is that the cooling time was found to be proportional to the square of the diameter of the cylinder when quenched in the theoretically most rapid coolant in which the surface of the metal is instantaneously cooled to the final temperature.

A theoretical study of the cooling of hot bodies in gases and liquids was more recently reported by Seeliger,[3] who reviewed several available theories and emphasized the fact that they do

[1] Refer to such texts as "An Introduction to the Mathematical Theory of Heat Conduction," by L. R. Ingersoll and O. J. Zobel (1913), Ginn & Co., New York, which includes references to original articles.

[2] K. Heindlhofer: Quenching: A Mathematical Study of Various Hypotheses on Rapid Cooling. *Physical Review*, 20, pp. 221-42 (1922).

[3] R. Seeliger: Die Abkühlung heisser Körper in Gasen und Flüssigkeiten. *Physik. Zeitschr.*, 26, p. 282 (1925).

not permit an exact solution but make possible useful deductions.

Experimental cooling curves of large sections have been obtained by a number of investigators. Fry[4] studied large solid and hollow-bored axles quenched in heavy and light oils, water, air and oil-water compounds, but due to differences in quenching temperature and the introduction of other variables into the several experiments, no general conclusions can be drawn. Law[5] investigated the cooling at the center of 18-inch cubes quenched in a water spray, a water bath, an oil and air, and likewise determined the resulting tensile properties from center to surface. The tensile strength gradients were greatest from the water bath quenching, but a maximum difference of only 1,000 pounds per square inch was found at the center in the cubes quenched in the various media (excepting air), thus indicating that the thermal properties of the steel have more to do with the center cooling in such large masses than the coolant used.

Bash[6] reported heating and air cooling curves taken at different points in a 24-inch ingot, while Knight and Hansen[7] studied the cooling at a point 2 inches from the edge of an 8-inch round, 14 feet long, when quenched in cottonseed oil.

Jantizky[8] devoted considerable attention to the experimental study of mass effects in heat treatment and developed a formula giving the relation between the hardness produced in various sizes and shapes of carbon and alloy steels when tempered at different temperatures subsequent to hardening. He also derived useful relations by which it is possible to approximate the time required to reach any temperature in air cooling rounds of various dimensions from different temperatures.

A feature of particular interest is that the surface per unit

[4]L. H. Fry: Notes on Some Quenching Experiments, *Journal*, Iron and Steel Institute, 95, p. 119 (1917).

[5]E. F. Law: Effect of Mass on Heat Treatment, *Journal*, Iron and Steel Institute, 97, p. 333 (1918).

[6]F. E. Bash: Forging Temperature and Rate of Heating and Cooling of Large Ingots. *Transactions*, American Institute of Mining Engineers, "Pyrometry" volume, p. 614 (1920).

[7]O. A. Knight and F. F. Hansen: Heating, Quenching and Drawing Large Steel Forgings, *Chemical and Metallurgical Engineering*, 20, p. 590 (1919).

[8]E. Janitzky: Hardness Formulas. *Iron Trade Review*, 69, p. 1079 (1921). Influence of Mass in Heat Treatment. *Chemical and Metallurgical Engineering*, 25, p. 783 (1921). Mass in the Heat Treatment of Steel. *Iron Age*, 109, p. 658; 110, p. 788 (1922). Influence of Size on Heat Treating. *American Machinist*, 50, p. 1153 (1919). A Contribution to the Problem of the Influence of Mass in Heat Treatment, TRANSACTIONS, American Society for Steel Treating, 2, p. 55 (1921). New Development on the Influence of Mass in Heat Treatment. TRANSACTIONS, American Society for Steel Treating, 2, p. 377 (1922). Characteristics of Air Cooling Curves, TRANSACTIONS, American Society for Steel Treating, 3, p. 335 (1922).

of volume, which in plates, rounds, and spheres is in the ratio of 1, 2, 3, when the ends and edges are neglected, is definitely related to the properties produced by quenching.

The effects of size on the tensile properties of quenched or quenched and tempered steels were studied by Zimmerschied[9] and by Straub.[10] While much useful information was obtained by both investigators, their results do not come within the field to be covered in this report, and, therefore, will not be reviewed in detail.

One of the most interesting points in published data was given by McCance,[11] who showed that the cooling velocity at the center of the high-carbon steel cylinders quenched in water by Portevin and Garvin,[11] when taken at a fixed temperature of 1290 degrees Fahr. (700 degrees Cent.) was inversely proportional to some power of the diameter greater than 1 but less than 2.

III. Experimental Methods Used

The methods of test employed were identical with those described in detail in a previous report.[12] Steel or other metal specimens of the desired form and dimensions were quenched from a definite temperature in known solutions and time-temperature cooling curves taken at the center of the samples with the aid of platinum platinum-rhodium thermocouples and a "string galvanometer."

Seven major sets of experiments were first carried out in which four coolants were used representing a wide range in "hardening power," viz., 5 per cent sodium hydroxide in water, water, a commercial quenching oil (referred to as No. 2 oil) and air. Steel specimens were all cooled from 1607 degrees Fahr. (875 degrees Cent.) and held motionless in the coolant which was at ordinary room temperatures (18 to 22 degrees Cent.). High-carbon steel (0.89 per cent carbon) rounds varying from ½ to 2 inches in diameter, but with a fixed length-diameter ratio of 4, were quenched

[9] K. W. Zimmerschied: Influence of Mass in Heat Treatment of Steel. *Iron Trade Review*, 53, p. 84 (1913).

[10] T. G. Straub: Relative Size in Heat Treatment, *Iron Age*, 104, p. 167 (1919).

[11] A. McCance: Discussion of Report by A. M. Portevin and M. Garvin. The Experimental Investigation of the Influence of the Rate of Cooling on the Hardening of Carbon Steels. *Journal*, Iron and Steel Institute, 99, p. 563 (1919).

[12] H. J. French and O. Z. Klopsch: Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treatment. TRANSACTIONS, American Society for Steel Treating, 6, p. 251 (1924).

in each of the four coolants; a group of ball-race steel spheres (0.98 per cent carbon, 1.63 per cent chromium), ¾ to 2⅞ inches in diameter, were quenched in water and another in the prepared oil, while high-carbon steel plates (from 0.85 to 1.15 per cent carbon), ⅜ to 2 inches thick, with a ratio of 4:4:1 in width, length and thickness, were cooled only in water. Subsequently, the effects of quenching temperature were investigated and experiments carried out with a large sphere and irregularly shaped pieces as given in the various sections of this report.

While several methods of comparison are referred to in discussing the effects produced by the different coolants, the primary one is the cooling velocity at 1330 degrees Fahr. (720 degrees Cent.), as it has already been shown that in quenching carbon steels this is the best single measure of "hardening power"[13] which can be secured from a cooling curve. It gave accurate information concerning the hardening produced and warranted retention, at least temporarily, for further experimental work.

IV. Experimental Results

1. Time-Temperature Cooling Curves

To illustrate the type of experimental data on which the various comparisons in this report are based, time-temperature cooling curves are reproduced in Fig. 1 for the center of spheres of various sizes quenched in water or in oil. These have been replotted directly from photographic records of the time-deflection changes in the "string galvanometer."

There are no striking variations in the character of the cooling curves obtained for the different sizes except for the location and magnitude of the heat effects of transformations. When at low temperatures these are small and do not appreciably change the cooling rates so no attempt has been made to indicate their position and magnitude in Fig. 1; they will readily be observed when large, as in the oil quenched spheres 2⅜ and 2¾ inches in diameter, because the resulting curves are quite different from those which would be obtained on a transformationless metal. This is clearly indicated by the dotted lines in Fig. 1. In no case, however, is the selected basis of comparison (the cooling velocity

[13]The term "hardening power" as used in this report refers to effects produced on the thermal transformations, microstructure and hardness of carbon steels by different media under otherwise comparable conditions of treatment. It is general in nature and considered to be proportional (qualitatively) to the cooling velocity at 720 degrees Cent. Thus the higher this cooling velocity the higher is the "hardening power."—See foot-note 12, page 36.

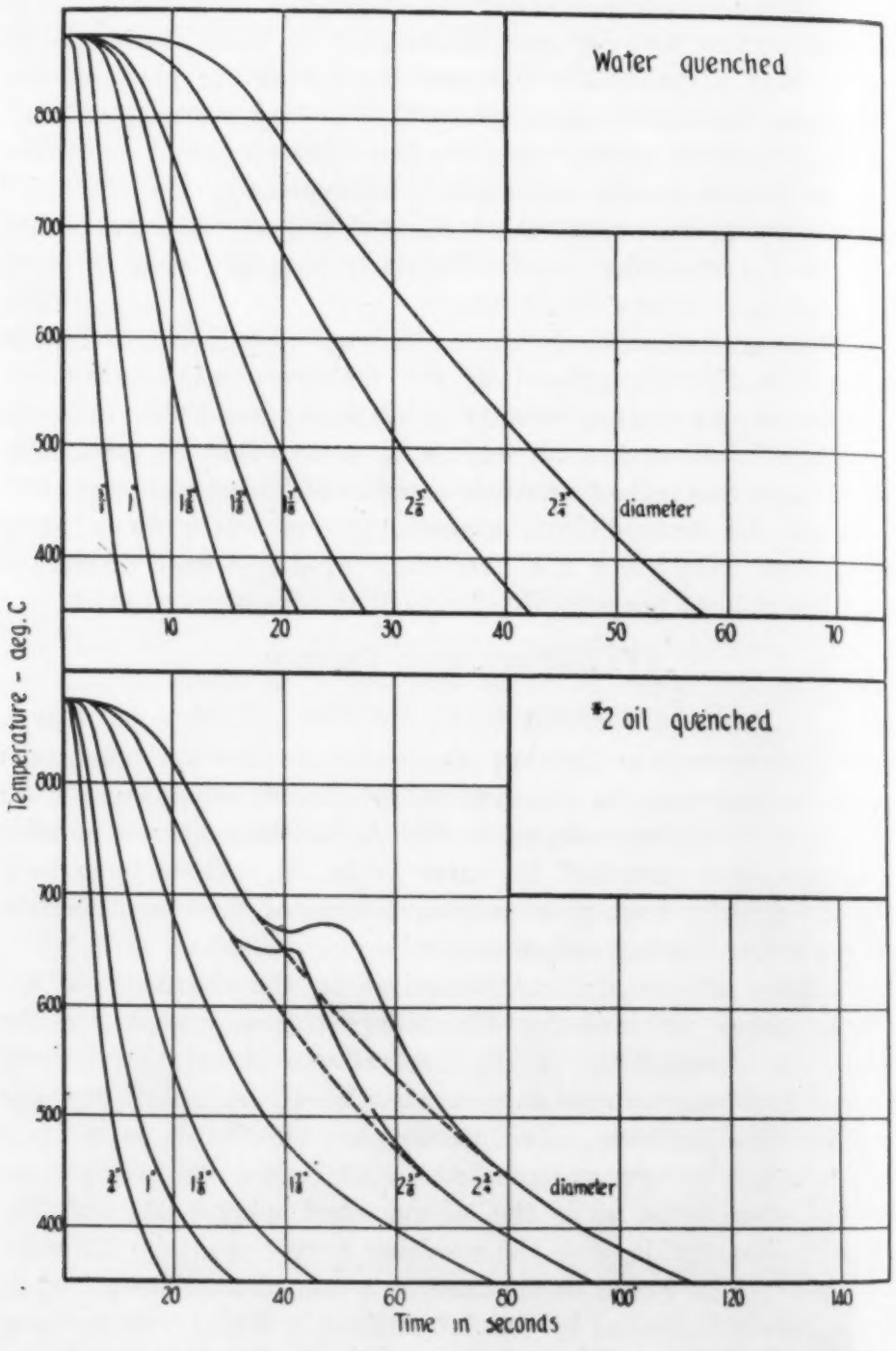

Fig. 1—Time-temperature Cooling Curves at the Center of Ball Race Steel Spheres of Different Sizes Quenched from 875 Degrees Cent. into either Motionless Water or No. 2 Oil at 20 Degrees Cent.

at 720 degrees Cent.) affected by any of these thermal effects, large or small, as they occur below this temperature.

The similarity in the cooling curves obtained in a given coolant on different sizes is, perhaps, more clearly shown in Figs. 2 and 3 by the changes in velocity with temperature. The maximum in a given coolant is found at one temperature for all sizes and the curves are of the same form; they differ only in the numerical values of the cooling rates and the magnitude of the changes in rate with temperature.

It is worthy of note that when quenching from the "standard" temperature of 1607 degrees Fahr. (875 degrees Cent.) into oil or water, the chosen basis for comparison (the cooling velocity at 720 degrees Cent.) is taken at practically the maximum speed of cooling. The changes in rate on either side of this maximum occur slowly, so that the cooling rate selected is being taken from a relatively flat portion of the curves and helps materially in giving exceedingly regular results.

The curves for air cooling in Fig. 3 show that the maximum velocity is much closer to the quenching temperature than in the case of either oil or water (Fig. 2) in which it occurs at about 0.8 of the initial temperature.

2. Effect of Size and Shape on the Center Cooling Velocity Taken at 720 Degrees Cent.

The effect of diameter in spheres and rounds, and thickness in plates, upon the center cooling velocity at 1330 degrees Fahr. (720 degrees Cent.) is shown in Fig. 4. The relation between the diameter or thickness and this cooling velocity is very closely approximated by the general equation

$$VD^n = c$$

in which V is the cooling velocity at 720 degrees Cent. in degrees Cent. per second, D is the stated dimension in inches (diameter for rounds and spheres, and thickness for plates) and "n" and "c" are constants, the values of which are given in Table I.

Comparison of these constants shows that the numerical value of the exponent "n" is a function of the coolant, while "c" is dependent upon the shape of the material as well, and hence upon the surface per unit of volume.

It may now be stated that in quenching:

(a) the cooling velocity, in the neighborhood of 1330 degrees Fahr. (720 degrees Cent.), at the center of spheres, rounds and plates is inversely proportional to some power of the diameter (or thickness) greater than 1 and less than 2.

(b) this power varies for the different coolants; it is close to 1 for air (1.15), approaches 2 in 5 per cent sodium hydroxide (1.84), and increases generally with the rapidity of the coolant.

At first glance it would appear that the value of the exponent

Table I

Numerical Values of the Constants for Equation (1)

Conditions	Value of "n"	Value of "c"
For ratio of length to diameter in rounds = 4 For ratio of length to width to thickness in plates = 4:4:1		
Rounds quenched in 5 per cent NaOH from 875 degrees Cent	1.84	61.3
Spheres quenched in water from 875 degrees Cent	1.75	89.8
Rounds quenched in water from 875 degrees Cent	1.75	54.1
Plates quenched in water from 875 degrees Cent	1.75	27.6
Spheres quenched in No. 2 oil from 875 degrees Cent	1.40	40.2
Rounds quenched in No. 2 oil from 875 degrees Cent	1.40	25.0
Rounds cooled in air from 875 degrees Cent	1.15	1.74

"n" in formula (1) might be used directly, or at least indirectly, to obtain a number truly expressing the "hardening power" of any coolant, as it is neither dependent upon the size nor the shape of the material. Such a derived value would, of course, be based on the assumption that the cooling velocity at 1330 degrees Fahr. (720 degrees Cent.) was a quantitative measure of the martensitization or hardening produced in any steel, which is not exactly true. Under ordinary conditions with carbon steels, it is a sufficiently close criterion, so that really large errors would not be introduced on this score, but there is another and more important reason why such a derived numerical value cannot be used. This will later be discussed in detail.

Some interesting and useful comparisons can be developed from the data given in Fig. 4. The first has to do with the effect of the shape of the steel on the center cooling velocity taken at

720 degrees Cent. (subsequently called "cooling velocity" or "cooling rate") and may be stated as follows:

(c) for a given size the highest cooling velocity is obtained in spheres, an intermediate rate in rounds and the lowest in plates.

This is due to the fact that a given size of sphere has a larger amount of surface per unit of volume by which the heat can be taken away than a round of the same diameter, and similarly a

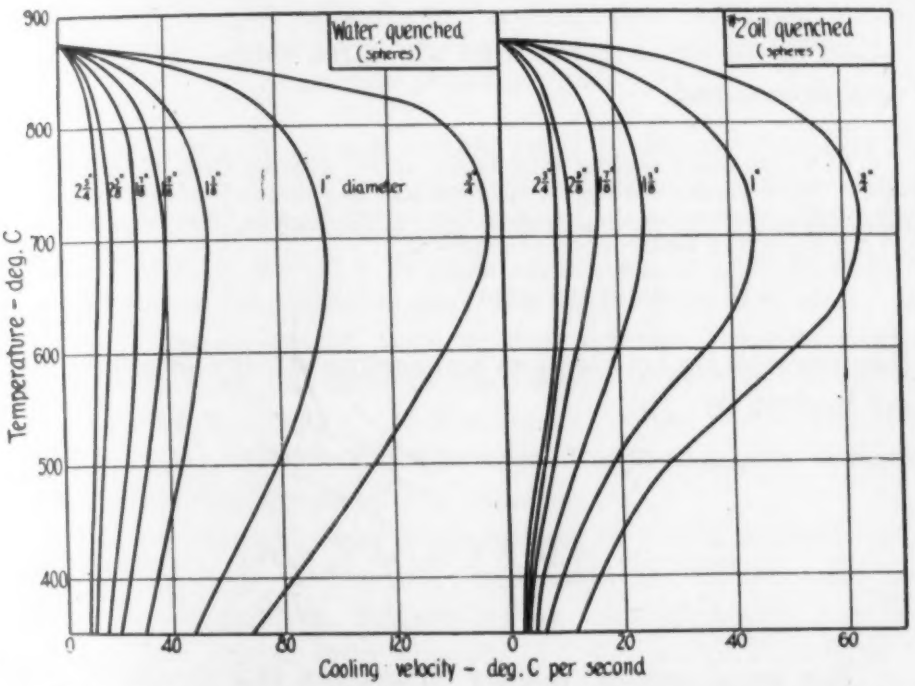

Fig. 2—Cooling Velocity-temperature Curves taken at the Center of Ball Race Steel Spheres of Different Sizes Quenched from 875 Degrees Cent. into either Motionless Water or No. 2 Oil at 20 Degrees Cent. The Transformations in the 2⅜ and 2¾" Diameter Spheres Quenched in Oil have been Disregarded in Plotting the Smooth Curves.

round has a larger surface per unit of volume than a plate of equal thickness. A more detailed consideration of the relation of the surface and surface per unit volume to the cooling velocity will be given in subsequent sections of this report.

A more generally useful and quantitative statement covering these relations is that

(d) for equal cooling velocity the ratio of the diameter of spheres to the diameter of rounds and thickness of plates is as 4: 3: 2, provided the length of the cylinder is 4

times its diameter and the length and width are each 4 times the thickness of the plate.

Thus the cooling velocity at 720 degrees Cent. and the hardening at the center of a 1 inch sphere are the same as in a ¾ inch round, 3 inches long, and a ½ inch thick plate, 2 inches long by 2 inches wide. Confirmation of this for certain sizes can be obtained directly from the experimental data tabulated in Table II, but more convincing proof can readily be secured mathematically from the general relationship given by formula (1), ($V D^n = c$); at the same time such computations will show the degree of accuracy attained in the experiments from which the values of "n" and "c" were determined.

If V_s = center cooling rate, taken at 720 degrees Cent. for spheres
V_r = center cooling rate, taken at 720 degrees Cent. for rounds
V_f = center cooling rate, taken at 720 degrees Cent. for plates
D_s = the diameter of the sphere
D_r = the diameter of the round
D_f = thickness of the plate

then the relation between size and cooling velocity in water quenching is given by

$$(2) \quad V_s D_s^{1.75} = 89.8 \text{ or } V_s = \frac{89.8}{D_s^{1.75}} \quad \text{for spheres}$$

and

$$(3) \quad V_r D_r^{1.75} = 54.1 \text{ or } V_r = \frac{54.1}{D_r^{1.75}} \quad \text{for rounds.}$$

For equal cooling velocity in spheres and rounds V_s equals V_r and

$$\frac{89.8}{D_s^{1.75}} = \frac{54.1}{D_r^{1.75}} \quad \text{or}$$

$$(4) \quad \frac{D_s}{D_r} = \left(\frac{89.8}{54.1}\right)^{\frac{1}{1.75}}$$

Here the right hand side of the equation (4) represents the ratio of diameters in spheres and rounds which will have the same cooling rate and when reduced is found to be equal to 1.333. Similar computations carried out for spheres and plates quenched in water give a ratio of diameters equal to 1.960; for spheres and rounds quenched in oil it is 1.399.

When these are compared to an assigned value of 4 to spheres, the following results are obtained which are equal, within limits of experimental error, to the stated ratios of 4:3:2.

	Ratio of diameters giving the same cooling rate at 720 degrees Cent. in	
	Water quench	Oil quench
Spheres	4	4
Rounds	3.00	2.86
Plates	2.04	..

3. *Data Showing That the Cooling Time for Certain Intervals is Inversely Proportional to the Cooling Velocity Taken at 720 Degrees Cent.*

It will probably be well at this point to demonstrate that the cooling velocity selected for previous comparisons is proportional to the cooling time, provided this is taken over an interval which does not begin or end at a temperature within the range of large heat effects of transformations. Not only does this make the foregoing comparisons of more general interest but also demonstrates again that the form of the cooling curves, or to express this somewhat differently, the manner of cooling at the center of spheres, rounds and plates, is not altered appreciably by variation in size (within the limits of the experiments).

In order to avoid those temperatures in which thermal effects would change both cooling rates and times and at the same time include in comparisons the cooling at both high and low temperatures, two ranges were selected, (1) the cooling time from the quenching temperature 1607 to 1290 degrees Fahr. (875 to 700 degrees Cent.), (2) the cooling time from 1607 to 750 degrees Fahr. (875 to 400 degrees Cent.).

As shown in Fig. 5 for spheres quenched in oil or in water, the relation between cooling time and diameter is closely approximated by a hyperbola having the general equation

$$\frac{T}{D^n} = c_1 \qquad (5)$$

in which T is the cooling time in seconds, D is the stated dimension in inches and "n" and "c_1" are constants.

The numerical value of "n" in this equation (5) is the same

as that in equation (1) for a given coolant. Therefore, the cooling time from either 875 to 700 degrees Cent. or 875 to 400 degrees Cent. is inversely proportional to the velocity and may be deter-

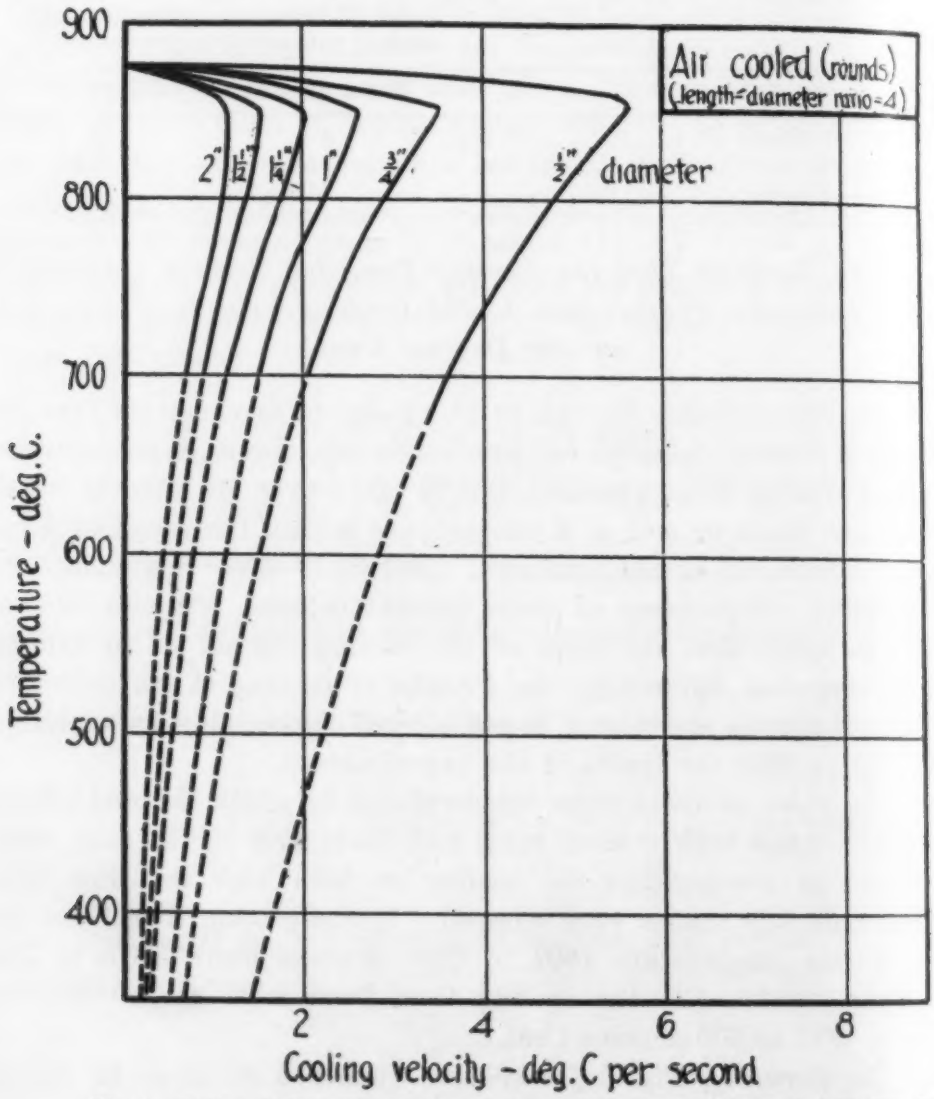

Fig 3—Cooling Velocity-temperature Curves taken at the Center of 0.89 Per Cent Carbon Steel Rounds of Different Sizes Cooled from 875 Degrees Cent. into Still Air at 22 Degrees Cent. Dotted Lines Indicate an Extrapolation in which the Heat Effects of the Transformations are Neglected.

mined if the values of "c" and "c_1" are known for the various shapes quenched in the different coolants. This may be expressed as follows:

$$T = \frac{c\ c_1}{V} \qquad (6)$$

in which "c_1" is the constant of equation (5) (cooling time for-

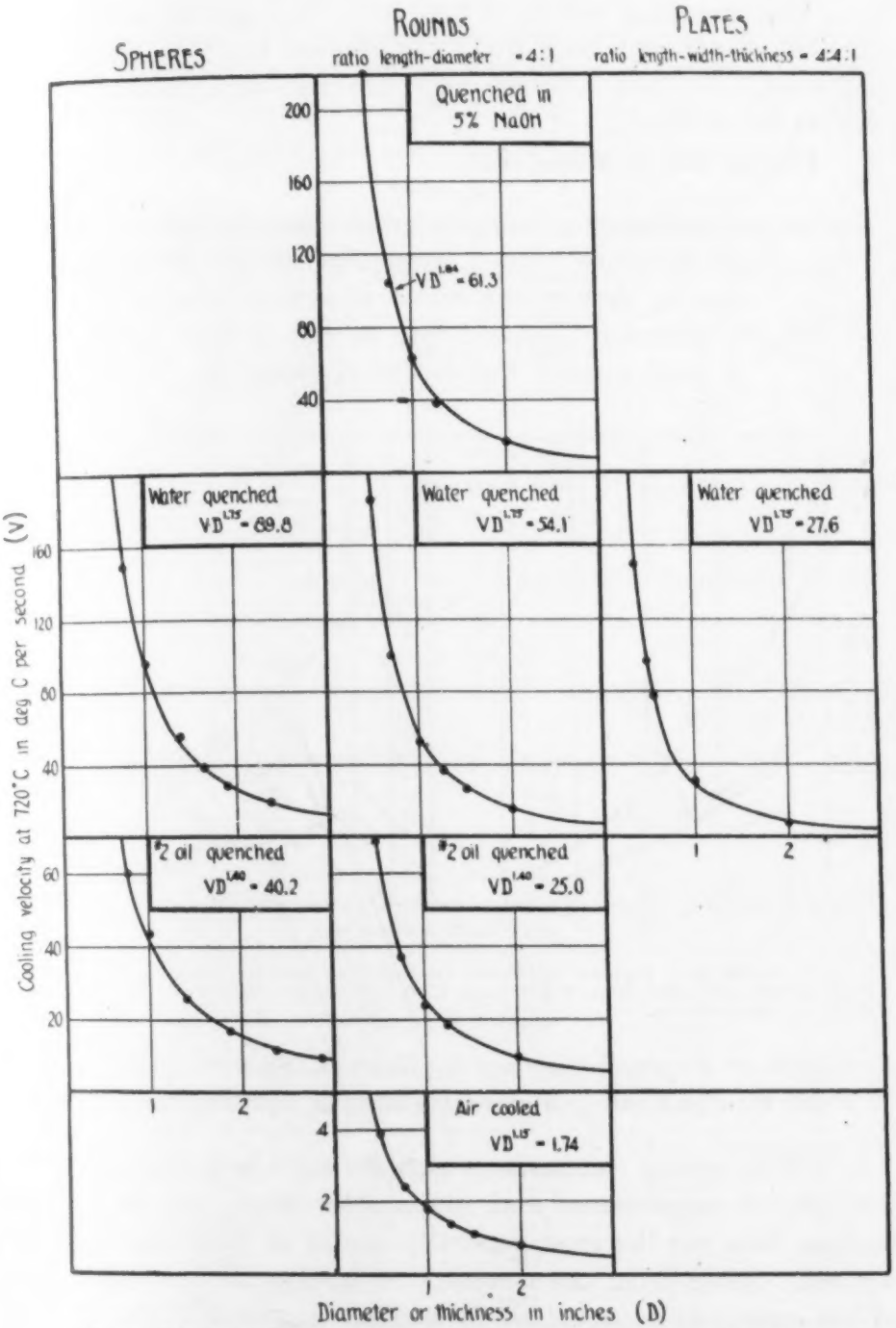
SPHERES
ROUNDS
ratio length-diameter = 4:1
PLATES
ratio length-width-thickness = 4:4:1
Quenched in 5% NaOH
VD^1.84 = 61.3
Water quenched VD^1.75 = 89.8
Water quenched VD^1.75 = 54.1
Water quenched VD^1.75 = 27.6
#2 oil quenched VD^1.40 = 40.2
#2 oil quenched VD^1.40 = 25.0
Air cooled VD^1.15 = 1.74
Cooling velocity at 720°C in deg C per second (V)
Diameter or thickness in inches (D)

Fig. 4—Relation Between the Center Cooling Velocity, taken at 720 Degrees Cent., and the Diameter or Thickness of High Carbon Steel Spheres, Rounds and Plates Quenched from 875 Degrees Cent. into Various Coolants.

mula) and "c" is the constant of equation (1) (cooling velocity formula).

The numerical values of "c" and "c_1" are, as previously indicated, dependent both upon the coolant and the shape of the material. On this account, they are not here included for all shapes and coolants.

It may now be stated that,

(e) provided the chosen interval does not begin or end at a temperature within large thermal transformations, the cooling time at the center of spheres, rounds and plates is inversely proportional to the cooling velocity taken at 1330 degrees Fahr. (720 degrees Cent.).

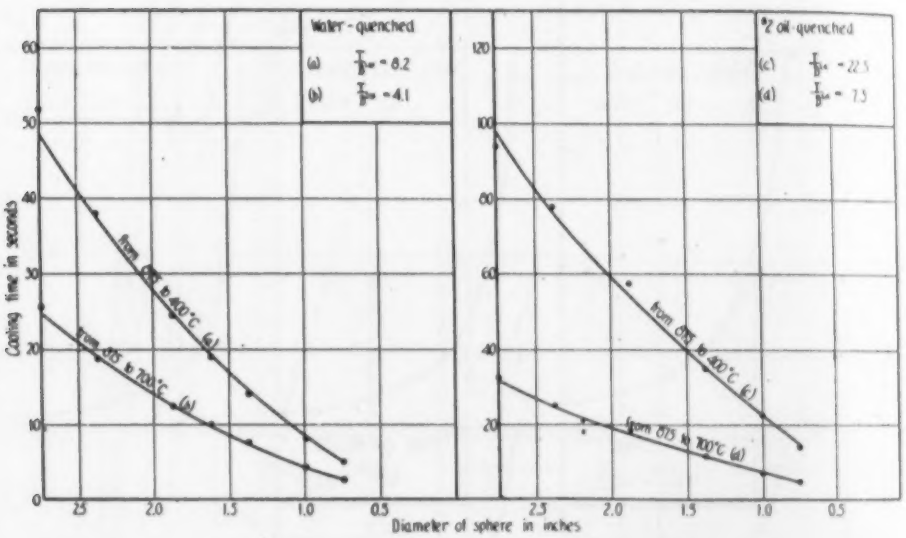
Water - quenched
(a) $\frac{T}{D^2}$ = 8.2
(b) $\frac{T}{D^2}$ = 4.1
% Oil - quenched
(c) $\frac{T}{D^2}$ = 22.5
(d) $\frac{T}{D^2}$ = 7.5
Cooling time in seconds
Diameter of sphere in inches
from 875 to 400°C (c)
from 875 to 700°C (a)
from 875 to 400°C (c)
from 875 to 700°C (a)

Fig. 5—Relation Between the Center Cooling Time and the Diameter of Ball Race Steel Spheres Quenched from 875 Degrees Cent. into either Motionless Water or No. 2 Oil at 20 Degrees Cent.

4. Effect of Exposed Surface in Rounds, Spheres and Plates on the Center Cooling Velocity, Taken at 720 Degrees Cent.

The foregoing comparisons and formulæ have been given for the sake of completeness and as a matter of general interest, not because they are the most generally useful of those which may be secured. Aside from the necessity of having the numerical value of the constants c (equation 1) and c_1 (equation 5) for each set of conditions involving change in shape and coolant, the relations do not apply directly to rounds having a length-diameter ratio other than 4, and likewise can only be used for plates in which the length and width are each 4 times the thickness. It is, there-

fore, desirable to seek a more generally applicable relation between the cooling rate and the size and shape of material.

In cooling a heated mass, heat must flow from the central

Table II

Experimental Data for the First Seven Sets of Quenching Experiments

0.98 per cent C, 1.63 per cent Cr, Steel Spheres quenched from 875 degrees Cent. into motionless coolants at 20 degrees Cent.

Size In.	Surface In.^{2}	Volume In.^{3}	Weight Grams	Ratio Surface Volume	Cooling Rate at 720° C. in °C. per sec. H_2O	Oil
3/4	1.767	.222	25.5	8	[a]148.5	[a]60
1	3.142	.523	64.	6	95	[a]43.5
1 3/8	5.91	1.326	170.5	4.46	55	[a]25.2
1 5/8	8.08	2.186	286.	3.70	39	...
1 7/8	11.05	3.450	438.	3.20	28	[a]16.6
2 3/8	17.50	6.790	894.5	2.58	20	[a]11.4
2.77	24.10	11.110	1425.	2.10	14	9

0.89 per cent Carbon Steel Rounds quenched from 875 degrees Cent. into motionless coolants at 20 degrees Cent.

Size In.	Surface In.^{2}	Volume In.^{3}	Weight Grams	Ratio Surface Volume	Cooling rate at 720° C. in °C. per sec. H_2O	No. 2 oil (b)	Air
1/2x2	3.53	.393	46.5	9	185	69	3.84
3/4x3	8.05	1.326	167	6	93	37	[a]2.37
1 x4	14.14	3.142	396	4.5	[a]52	23.5	1.77
1 1/4x5	22.09	6.135	780	3.6	[a]37	18.5	1.36
1 1/2x6	31.81	10.602	1350	3.0	[a]27.4	....	1.07
2 x8	56.53	25.13	3195	2.25	15.3	9.4	.80

Size In.	Surface In.^{2}	Volume In.^{3}	Weight Grams	Ratio Surface Volume	Cooling rate at 720° C. in °C. per sec. 5% NaOH
1/2x2	3.53	.393	46.5	9	222
.744x2.98	7.84	1.295	161.2	6.05	105
.99x3.98	13.92	3.065	383.5	4.54	64
1.24x4.96	21.77	5.980	760.0	3.64	37
1.99x7.98	56.12	24.83	3156.	2.26	16.8

High Carbon Steel Plates quenched from 875 degrees Cent. into water at 20 degrees Cent.

Size In.	Surface In.^{2}	Volume In.^{3}	Weight Grams	Ratio Surface Volume	Cooling rate at 720° C. in °C. per sec. H_2O
3/4x3/8x1 1/2	6.75	.844	104.1	8	149
1/2x2x2	12.00	2.00	253.0	6.00	97
2/16x1/16x2 1/4	15.19	2.85	353.0	5.33	[a]77
1x4x4	48.0	16.00	2026.	3.00	31
2x7.89x7.92	188.04	125.00	15961	1.51	6.9

(a) Average of 2 values.
(b) No. 2 oil is a prepared commercial quenching oil, the same as referred to in a previous report. Refer to footnote (12) of the text.

zone toward the surfaces and be taken away from the body through the surface of the metal which is in direct contact with the coolant.

Under ordinary conditions of heat treatment there is an unlimited supply of the coolant in comparison with the mass of metal to be cooled, so that the time required to take the heat away, and hence the rate of extraction, will be a function of the amount of heat to be removed. With a fixed initial (quenching) temperature this is proportional to the volume of a given metal. Since the exposed surface and volume are both of importance in determining the cooling rate in a given coolant, it is reasonable to expect that the most general relation will be found in comparison of the surface per unit volume and the cooling velocity and not in consideration of the amount of surface alone.

While the surface-cooling velocity curves for the different shapes, as shown in Fig. 6, are of the same general type as those in Fig. 4, in which diameter or thickness is plotted against the cooling velocity, it can readily be shown that they apply only to the specific sets of conditions covered by the experiments and are not of more general use. Therefore, no attempt has been made to represent these curves mathematically.

5. Relation Between the Surface Per Unit of Volume and the Cooling Velocity, Taken at 1330 Degrees Fahr. (720 Degrees Cent.)

If the cooling velocity, taken at 720 degrees Cent., is compared to the surface per unit of volume for each of the basic shapes (spheres, rounds and plates) a family of hyperbolic curves is obtained which are closely approximated by

$$V = \left(\frac{S}{W}\right)^n \times C_2 \qquad (7)$$

where V is the cooling velocity in degrees Cent. per second, taken at 720 degrees Cent., S is the surface area in square inches, W is the volume in cubic inches and "n" and "C_2" are constants, the values of which are given in Table III ("n" is the same as in previous equations).

Unlike previously developed relations, both constants are independent of the shape of the material and, under otherwise fixed conditions, are determined solely by the coolant. This, however, only applies to the simple and basic shapes covered by the experiments, namely, spheres, rounds and plates, but is not re-

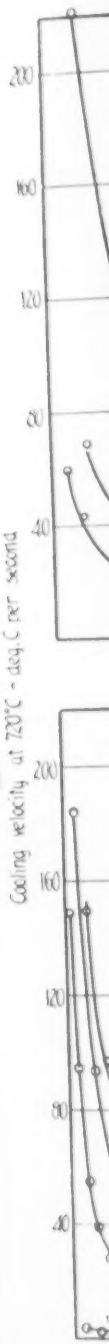

Fig.
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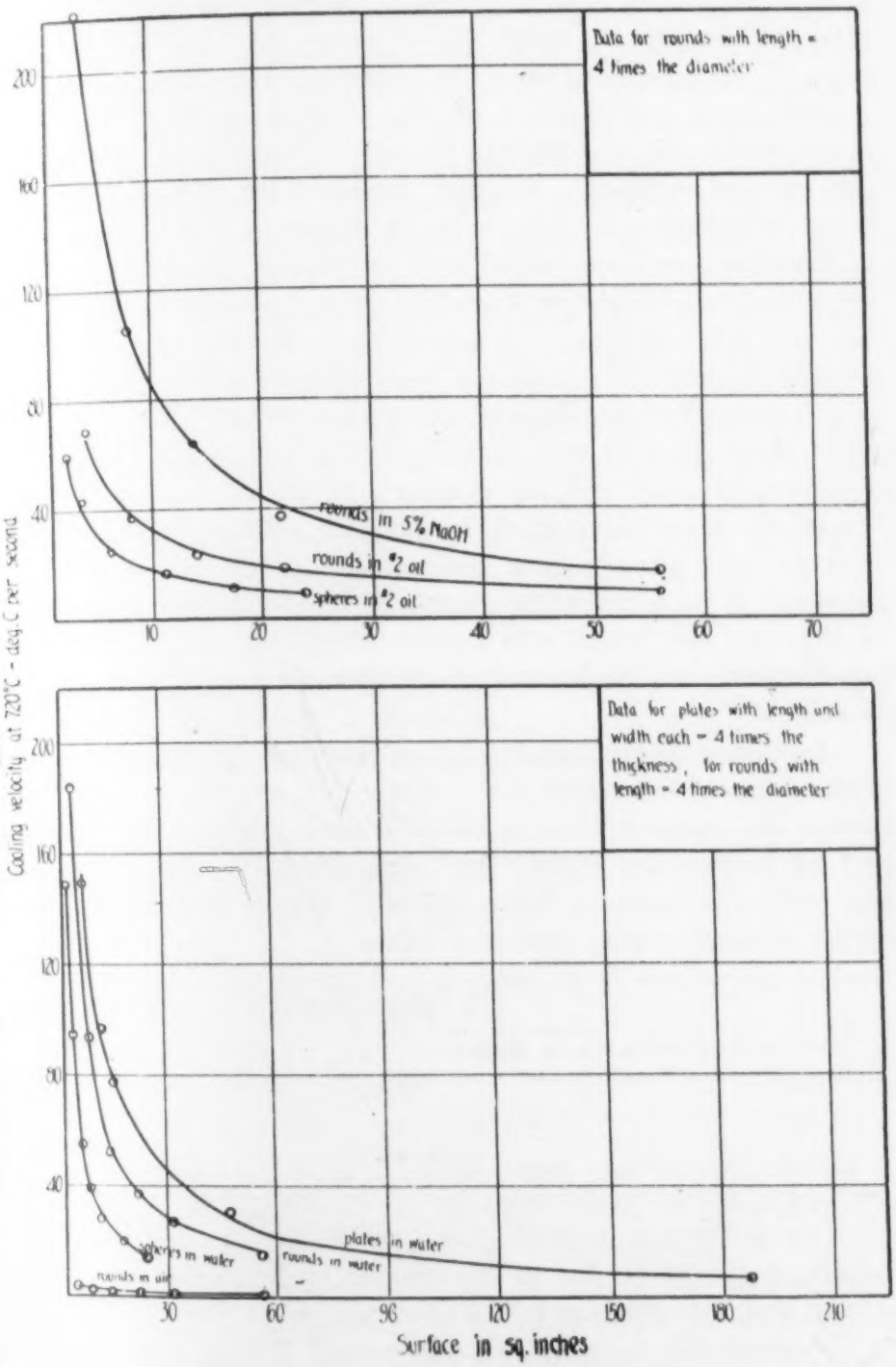

Data for rounds with length = 4 times the diameter
rounds in 5% NaOH
rounds in #2 oil
spheres in #2 oil
Data for plates with length and width each = 4 times the thickness, for rounds with length = 4 times the diameter
plates in water
rounds in water
spheres in water
rounds in air
Cooling velocity at 720°C - deg. C per second
Surface in sq. inches

Fig. 6—Relation Between the Center Cooling Velocity, taken at 720 Degrees Cent. and the Exposed Surface in Quenching Various Sizes and Shapes in Different Coolants from 875 Degrees Cent.

stricted to a fixed ratio of length to diameter in the rounds or a ratio of length to width to diameter in the plates. Formula (7) is thus more generally applicable than the previous ones. Experimental confirmation of this is given in Fig. 7, in which is shown the effect of surface per unit volume on the cooling rate for various coolants. Spheres, rounds with different ratios of length to diameter, and plates in which the ratio of length to width to diameter has been varied, are all plotted to the same coordinates and fall closely on a smooth curve for each coolant. From the data given in Fig. 7, it is possible to approximate the cooling velocity for any of the simple basic shapes, or this can be determined from formula (7) and the values of "n" and "C_2" given above for 5 per cent sodium hydroxide in water, water, a commercial quenching oil and air cooling. If the critical cooling rates are known for a given steel, or quenching diagrams are available such as have already been determined for carbon steels by the authors,[14] it follows that the degree of hardening can be predicted, or that the size which will harden completely throughout (martensitization) can be determined, whether for a round, sphere, plate or cube.

Inasmuch as "n" and "C_2" of formula (7) are independent of the shape of the material the center cooling velocities of spheres, rounds and plates will be equal when their respective surfaces per unit of volume are equal. The sizes which have equal surfaces per unit of volume in these different shapes and, hence, equal center cooling velocity, are as follows:

	Size in inches for	
Length-diameter ratio for rounds =	4:1	infinite
Length-width-thickness ratio for plates =	4:4:1	infinite
Spheres	4	3
Rounds	3	2
Plates	2	1

The difference between these ratios for the finite and the infinite specimens is due to the greater cooling effect exerted by the end and edge surfaces of the short pieces.

To apply the foregoing to any coolant it is only necessary to know, for different values of surface per unit of volume, the relation between "n" and the cooling velocity. This is shown graphi-

[14]Refer to note (12).

cally by the family of curves in Fig. 8 and can conveniently be used for any of the simple shapes. For example, if the prescribed cooling velocity is known when quenching a cylinder 1 inch in diameter and 6 inches long in a special oil, the numerical value of "n" for this coolant is given by the intersection of the horizontal line at this cooling rate and the curve representing the surface per unit of volume of a cylinder 1 inch round by 6 inches long. Let it be assumed that the cooling velocity is known to be 25 degrees Cent. per second. Since the surface per unit of volume of the designated cylinder is 4.33, the value of "n" equals 1.43.

By substitution in equation (7) the constant "C_2" can readily be obtained, and it is then possible to make use of the formula in the usual manner. However, the determination of "C_2" is not necessary. Knowing the value of "n" for the coolant, it is possible to scale directly from the curves in Fig. 8, the cooling velocity for any value of surface per unit of volume. These lie along a vertical line projected from 1.43 which equals the value of "n."

Fig. 8 gives the most useful of the relationships so far developed, for with it a close approximation can be obtained of the mass effects in quenching for a wide range of conditions. No calculations are required and it is only necessary to know the center cooling velocity for one size in any of the simple shapes.

Table III

Numerical Values of the Constants for Equation (7)

Conditions	Value of "n"		Value of "C_2"
Rounds quenched in 5 per cent NaOH from 875 degrees Cent	1.84		3.86
Spheres quenched in water from 875 degrees Cent	1.75		3.89
Rounds quenched in water from 875 degrees Cent	1.75		3.91
Plates quenched in water from 875 degrees Cent	1.75		4.03
		Av.	3.94
Spheres quenched in No. 2 oil from 875 degrees Cent	1.40		3.22
Rounds quenched in No. 2 oil from 875 degrees Cent	1.40		3.03
		Av.	3.12
Rounds cooled in air from 875 degrees Cent	1.15		0.31

It will be well at this point to refer again to the conditions under which the described experiments were carried out so that there will be no misunderstanding concerning the limits within which the various data may be applied. In the first place, the

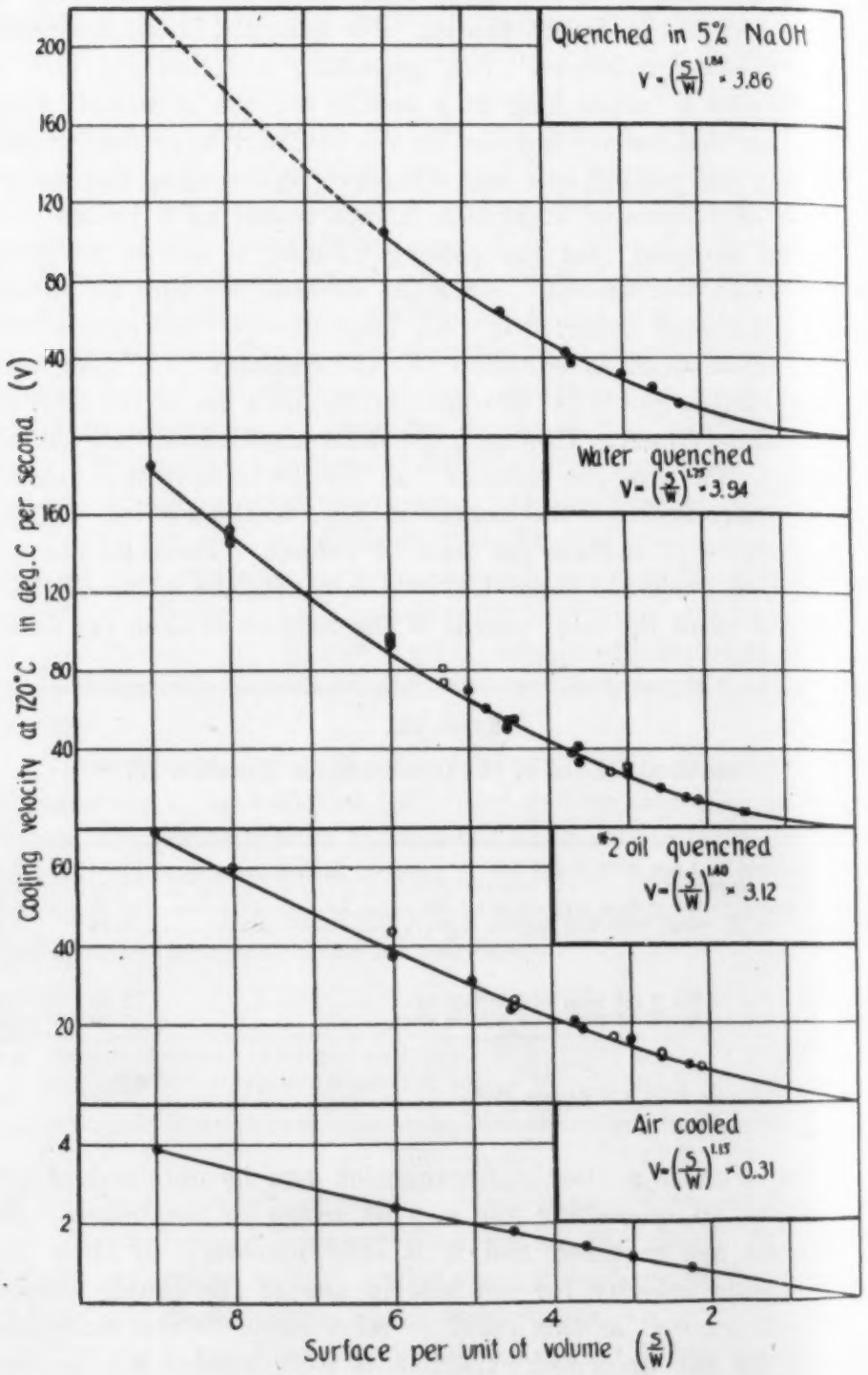


Fig. 7—Relation Between the Surface per unit of Volume and the Center Cooling Velocity, taken at 720 Degrees Cent. in Various Sizes and Shapes Quenched from 875 Degrees Cent. into Different Coolants. Hollow Circles Represent Determinations with Spheres; Solid Circles with Rounds; Hollow Squares with Plates.

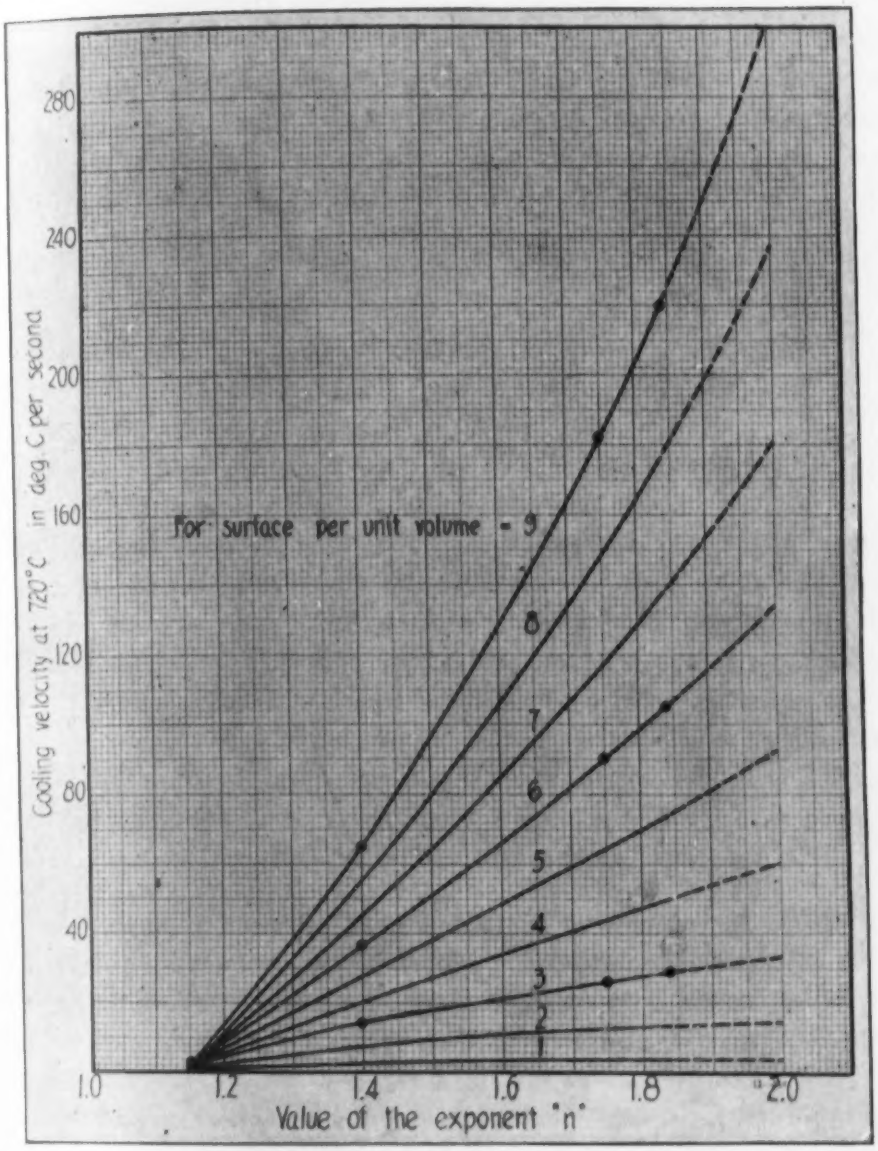


Fig. 8—"Mass Effect Chart." This Gives the Relation Between the Center Cooling Velocity, taken at 720 Degrees Cent., the exponent "n" of Formula (7), and the Surface per unit of Volume for High Carbon Steels Quenched from 875 Degrees Cent. into any Coolant.

relations have so far only been shown to apply to the effects at the center of the simple basic shapes. For a complete understanding of the mass effects in quenching, a study must also be made of the temperature distribution, and it is expected that this phase will be covered in a subsequent report. In all cases a quenching temperature of 1607 degrees Fahr. (875 degrees Cent.) was employed and both the steel and the coolant were kept motionless.

As the customary methods of commercial treatment for relatively small sections involve agitation or circulation of liquids such as water and oils, and likewise employ a variety of quenching temperatures which depend largely upon the composition of the steel as well as the purpose of the treatment, practical application of the developed data requires consideration of these two variables: (1) the effect of motion in coolants on the cooling velocity and (2) the effect of quenching temperature on this cooling velocity.

Just as water and oil are different coolants so may each rate of motion or degree of circulation be properly considered as distinct from the motionless coolant. On the assumption that the rate of motion changes the speed of cooling there are, therefore, an infinite variety of coolants which must be considered, including not only changes in the composition but also in degree of motion and temperature. As already stated, it is only necessary to have available the described cooling velocity for a known size and shape of high carbon steel quenched from 1607 degrees Fahr. (875 degrees Cent.) into a given coolant in order to determine from Fig. 8 the constant "n" and all data which can be developed for the motionless media used in the experiments. The accuracy of the results will, of course, be dependent upon the reliability of the cooling rate used as a basis for comparisons or calculations.

The described data may now be summarized:

(f) In quenching simple shapes of various sizes, (spheres, rounds, plates) the center cooling velocity is proportional to some power of the surface per unit of volume greater than 1 and less than 2. This power increases with the rapidity of the coolant used.

(g) When quenching from a definite temperature into a given coolant the center cooling velocity is determined by the exposed surface per unit of volume. Hence, it will be equal in spheres, rounds and plates which have equal surface per unit of volume. This condition is fulfilled when the ratio of diameters of spheres and rounds of infinite length to the thickness of plates having infinite width and length is 3:2:1. When the length of the round is 4 times its diameter, and the width and length are each 4 times the thickness of the plate, these ratios become 4:3:2.

6. *Effect of Quenching Temperature on the Center Cooling Velocity Taken at 1330 Degrees Fahr. (720 Degrees Cent.)*

The effect of quenching temperature on the designated cooling velocity obtained in water and two oils is shown graphically in Fig. 9, and it will be noted that in all cases the increase in rate is much more marked for a given temperature rise between 1330 to 1470 degrees Fahr. (720 and 800 degrees Cent.) than above. From these curves, conversion factors can be determined by which it is possible to change the cooling rates from the "standard" quenching temperature of the experiments, 1607 degrees Fahr. (875 degrees Cent.), into the rates which would be obtained from any initial temperature between 1330 and 1920 degrees Fahr. (720 and 1050 degrees Cent.), a range covering commercial hardening except for high speed steels. As a matter of convenience the conversion factors are shown graphically in the right half of the diagram.

In addition to the direct experimental observations giving the changes in rates with quenching temperature, derived values for the conversion factors have been included in the curve at the right side of Fig. 9. These were computed from data given in Fig. 2 and depend upon two facts: (1) the cooling velocity-temperature changes (neglecting thermal transformations) are of the same form when quenching the various sizes and shapes from different temperatures in a given coolant, and (2) for a given final temperature, the maximum velocity throughout the cooling ranges is directly proportional to the initial (quenching) temperature, both with respect to its position in the temperature scale and its numerical value.

The many quenching curves taken to demonstrate these features cannot be included in this report nor will there be given in detail the derivation of the conversion factors by this method. It is to be noted, however, that the derived values show close agreement with those determined directly by experiment, and thus indicate that exceptionally consistent results have been obtained in the several sets of experiments.

The actual change in cooling velocity is larger in the rapid coolant than in those which cool the steel more slowly, but the conversion factors for the two oils and water are practically identi-

cal; at least, they are so close as to be within the limits of experimental accuracy.

From the data given in Fig. 9 "the quenching temperature conversion chart" of Fig. 10 has been prepared.

This gives, for samples of different surfaces per unit of volume, the conversion factors to be applied to the cooling velocity from one quenching temperature in order to determine the cooling velocity of the same sample when quenched in the same coolant from any other temperature between 1330 and 1920 degrees Fahr. (720 and 1050 degrees Cent.).

It applies generally to any coolant which gives cooling characteristics similar to those shown in Fig. 2. Practically, all of the oils and aqueous solutions so far tested at ordinary temperatures fulfill these conditions within the limits of accuracy attained in the described experiments. Included in this list are sodium hydroxide solutions, sodium and also calcium chloride brines, dilute sulphuric acid, sperm, neatsfoot, transformer, cottonseed, machine, castor, olive, fish, and three commercial quenching oils. It does not, however, apply to air cooling.

In connection with Fig. 10, the "mass effect chart" (Fig. 8) becomes of very general use as it is only necessary to reduce the known value of the cooling velocity from one quenching temperature into the rate produced from 1607 degrees Fahr. (875 degrees Cent.) when the mass effects can be determined and a reconversion for quenching temperature made for the new size and shape. To illustrate the use of the "quenching temperature-conversion" chart, a number of examples may be cited.

If the rate for a ½ inch round, 2 inches long (surface per unit volume = 9) is known to be 67 degrees Cent. per second when quenched in a given coolant from 1650 degrees Fahr. (900 degrees Cent.) and it is desired to determine the rate when quenching from 1400 degrees Fahr. (760 degrees Cent.) under otherwise comparable conditions the following procedure is employed:

First obtain in Fig. 10 the intersection between the $\frac{S}{W}$ curve = 9 with the quenching temperature of 900 degrees Cent. The factor opposite this intersection is 1.03. Next follow the $\frac{S}{W}$ curve = 9 in the direction of and until it intersects the new quenching temperature of 760 degrees Cent. The factor oppo-

site this intersection is 0.59. The cooling velocity when quenching from 760° C. will then be $\frac{0.59}{1.03}$ of that when quenching from 900 degrees Cent. or $\frac{0.59}{1.03}$ x 67 = 38 degrees Cent. per second.

The described procedure is shown by the dotted lines in the chart.

A more complicated case in which both the "mass effect"

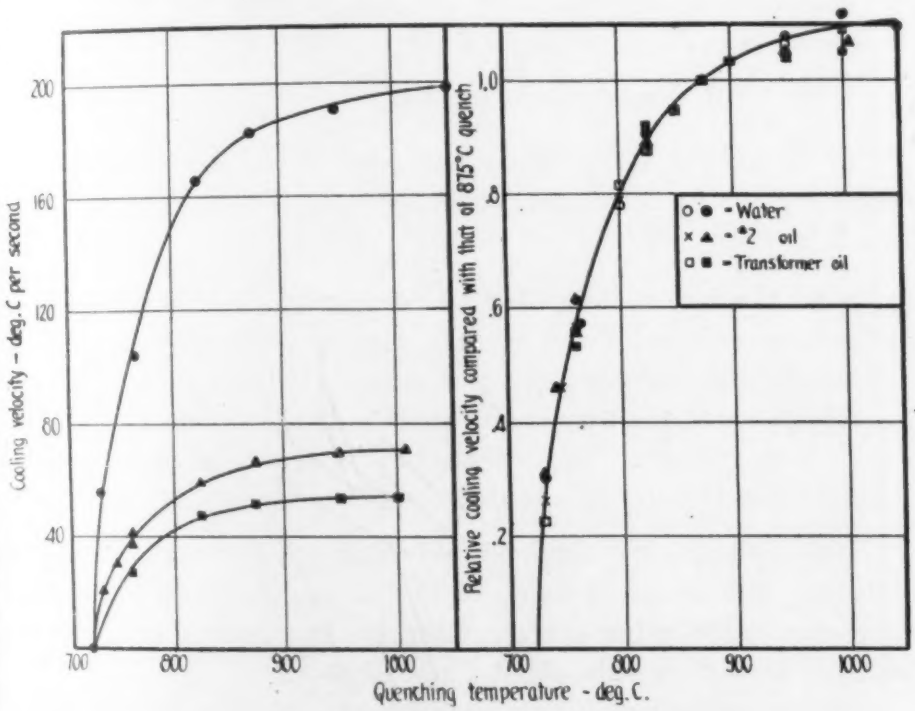


Fig. 9—Effect of Quenching Temperature on the Center Cooling Velocity, taken at 720 Degrees Cent. in Quenching High Carbon Steel into either Motionless Water or Oils at 20 Degrees Cent. Direct Experimental Results given as Solid Circles, Triangles and Squares. Derived Values, as Explained in the Text, are Shown by Crosses and Hollow Circles and Squares.

and "temperature conversion" charts are used will now be followed and checked by actual experiments.

The selected cooling velocity for a ¾ inch round, 3 inches long (surface per unit of volume = 6) when quenched from 1455 degrees Fahr. (790 degrees Cent.) into 5 per cent sodium chloride, was found by experiment to be 76 degrees Cent. per second. It is desired to determine the cooling velocity in a ½ inch round, 2 inches long (surface per unit of volume = 9) when quenched

from 1607 degrees Fahr. (875 degrees Cent.) into the same coolant. The following procedure is used.

(1) First make the temperature conversion from 1455 to 1607 degrees Fahr. (790 to 875 degrees Cent.) from Fig .10.

Find the intersection between the curve $\frac{S}{W} = 6$ and the quenching temperature of 790 degrees Cent. The factor opposite is 0.37. Next follow on this $\frac{S}{W}$ curve to the right until it intersects 875 degrees Cent. The factor opposite this intersection is 0.49. The cooling velocity when quenching the ¾ inch round, 3 inches long from 875° C. will then be $\frac{0.49}{0.37}$ x 76 = 101 degrees Cent. per second.

(2) Convert this new cooling rate of 101 degrees Cent. per second for the ¾ inch round into the rate for the ½ inch round from Fig. 8.

Find the intersection of the line representing the surface per unit of volume of the ¾ inch sample (=6) with the cooling rate of 101 degrees Cent. per second. Follow vertically from this point to the new surface per unit of volume (=9 for the ½ inch round). The intersection is found to be opposite to a cooling velocity of 211 degrees Cent. per second.

The cooling rate obtained experimentally for the described conditions was found to be equal to 215 degrees Cent. per second, which checks the value derived from the two charts, (211 degrees Cent. per second) within about 2 per cent.

Other comparisons between values derived from the two charts and experiment are given in Table IV and show that consistent agreement is secured.

7. *General Limits Within Which the Derived Relations Between the Cooling Velocity and the Surface Per Unit of Volume Apply*

There still remains for discussion the limits within which the derived relations between the cooling velocity and surface per unit of volume apply. Definite limits cannot be set at this time but the results of a few special experiments will serve to illustrate some of the principles involved.

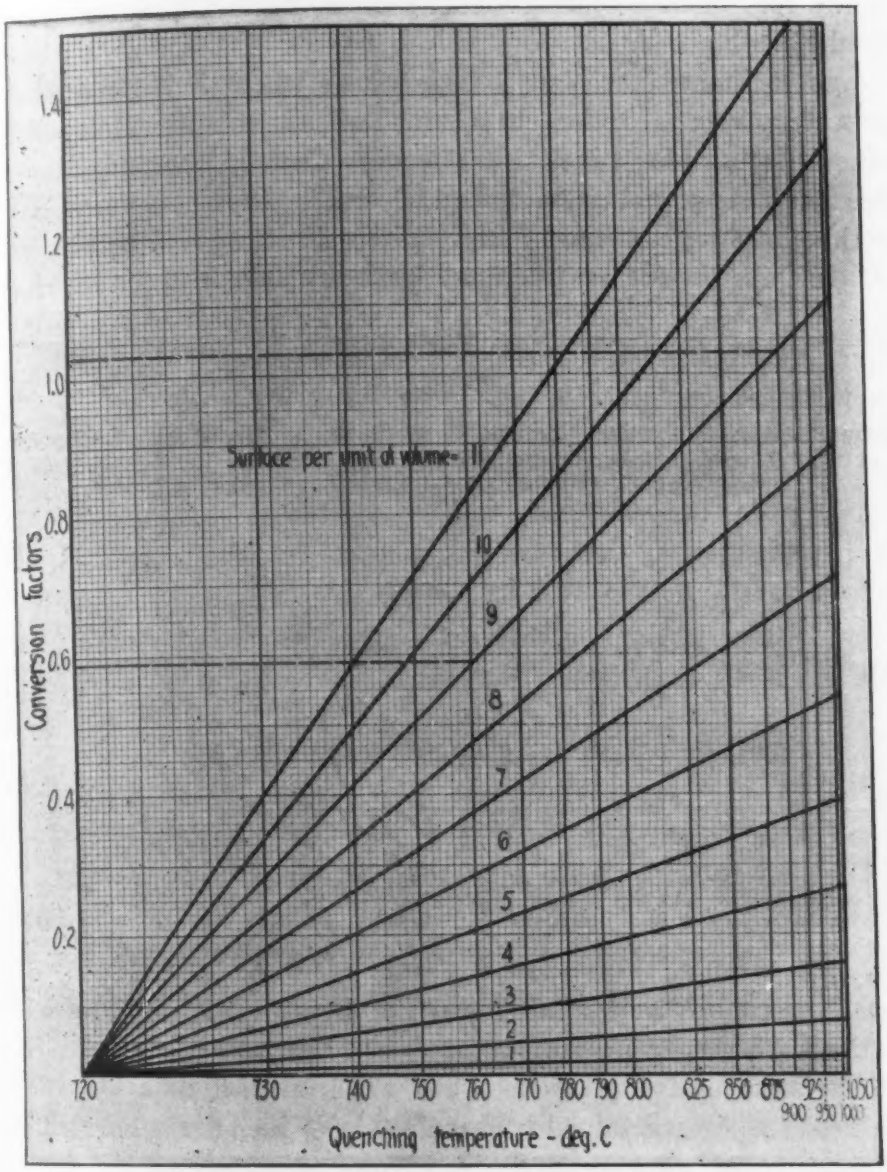


Fig. 10—"Quenching Temperature Conversion Chart." This gives the Relation Between the Quenching Temperature and Center Cooling Velocity, taken at 720 Degrees Cent., for Various Sizes and Shapes of Steel with the Oils and Aqueous Solutions having Cooling Characteristics Similar to those shown in Fig. 2.

A 1 inch diameter cylinder, 3½ inches long, with spherical ends was quenched in water from 1607 degrees Fahr. (875 degrees Cent.) and the center cooling velocity found to be 55 degrees Cent. per second. This cylinder has a surface per unit of volume equal to 4.42 and according to formula (7) the cooling velocity would be 53 degrees Cent. per second. Its surface per unit of volume is slightly less than the same cylinder without the spherical ends

(4.56) for which a cooling velocity of 56 degrees Cent. per second should be obtained.

A 7/8 inch square bar 3 inches long when similarly quenched in water from 875 degrees Cent. had an experimentally determined cooling rate equal to 60 degrees Cent. per second. Its surface per unit of volume equals 4.80 and according to formula (7) or the chart reproduced in Fig. 8, its velocity should be 61.

In both these cases the modifications made in the basic shapes

Table IV

Comparison of direct experimental determination for cooling velocity taken at 720°C with values derived from "Mass Effect" and "Quenching Temperature Conversion" Charts. (Figs. 8 and 10)

(1) Sample	(2) Surface per unit volume	(3) Coolant	(4) Quenching Temp. °Cent.	(5) Cooling Velocity at 720° C. by Experiment	Cooling Velocity at 720° C. When Quenching from 875° C. (6) Converted to $\frac{S}{W} = 9$ by Means of Tables 8 and 10	Cooling Velocity at 720° C. When Quenching from 875° C. (7) Direct Experimental Determination for $\frac{S}{W} = 9$	Variation of (6) from (7) in per cent
¾"x3" Round	6	5% NaCl	790	76	211	215	2.
¾"x3" Round	6	H_2O	800	69	174	182	4.5
¾"x3" Round	6	Transf. Oil	790	19	54	51	5.5
2¾" Sphere	2.1	H_2O	760	8.3	186	182	2.0
2¾" Sphere	2.1	No. 2 Oil	760	4.6	65	66	1.5

(spheres, rounds and plates) did not involve very large changes in the surface per unit of volume and the values obtained from the formulæ and charts check the experimental data within the limits of accuracy attained. Therefore, a ¾ inch diameter cylinder, 3 inches long, was prepared in which the entire curved surface was threaded with ¾ inch U. S. Standard threads, 10 to the linear inch. The surfaces per unit of volume of this threaded specimen and an unthreaded cylinder of the same length and diameter are respectively 11.0 and 6.0. The calculated cooling velocity for the threaded piece is 505 degrees Fahr. (262 degrees Cent.) per second, whereas the actual rate obtained in quenching was only 92 degrees Cent. per second, which is practically identical with the calculated and actual cooling velocity of the plain cylinder, namely, 90 degrees Cent. per second.

No general conclusions can be drawn from such limited experiments, but they indicate that the described relations between cooling velocity and the surface per unit of volume do not apply when modifications in the simple basic shapes involve a large change in the surface without appreciably affecting the volume (or weight). With slight changes in form from the basic shapes which do not alter materially the ratios of surface to volume, the formulæ and charts will give results which approximate the actual values within about 5 per cent.

Obviously, they cannot be considered for irregularly shaped masses which have no geometrical center at which to determine the cooling velocity, but in at least some of such cases it is reasonable to expect that the cooling velocity at the center of equal temperature planes would bear some definite relation to the surface-volume relationship. This might profitably be investigated but would require a study of temperature distribution during cooling.

Another and more important question, as it relates to the simple shapes covered by the experiments, is whether the data can be applied to very large masses.

It has already been demonstrated that the relation between the center cooling velocity and the surface per unit of volume is represented by a family of hyperbolic curves having the general formula $V = \left(\frac{S}{W}\right)^n C_2$. As the value of the exponent "n" was found to vary for the different coolants the curves will cross if carried far enough to include very large sizes.

In other words, oil would cool faster than water, and with sufficiently large masses even air would cool the centers more rapidly than sodium hydroxide, etc. Obviously, such effects are unreasonable, and it may be stated at the outset that the several equations given in this report do not hold good in such cases. However, it is quite reasonable for the center cooling velocity given by various coolants to be more nearly the same for large sections than in the relatively small samples used in the described experiments. A point must be reached with increasing mass where the effective surface through which the heat must be taken is so small in relation to the weight (or volume), and so far removed from the center that the cooling is a function of the thermal properties of the metal. No matter how quickly the surface is brought to the

final temperature of cooling there must be a limiting rate by which heat can be withdrawn from the center and this is controlled by the thermal properties of the material being quenched.

a. Results Obtained in Quenching a Sphere 11¼ Inches in Diameter.

To determine whether equal cooling velocities are obtained under such conditions, in which the formulæ show a supposed reversal of "hardening power" for various coolants, and likewise to compare the numerical values of cooling rates determined experimentally on large sections with those derived from the small size specimens, three quenching experiments were carried out with a sphere 11.25 inches in diameter. This was quenched from 1805 and 1877 degrees Fahr. (985 and 1025 degrees Cent.) into motionless water at 22 degrees Cent. and also from 1805 degrees Fahr. (985 degrees Cent.) into motionless 5 per cent sodium hydroxide at 22 degrees Cent. A 14-gage chromel-alumel thermocouple and a portable potentiometer were used in taking the time-temperature cooling curves reproduced in Fig. 11. Aside from the inconvenience in using the string galvanometer for low rates of cooling, this

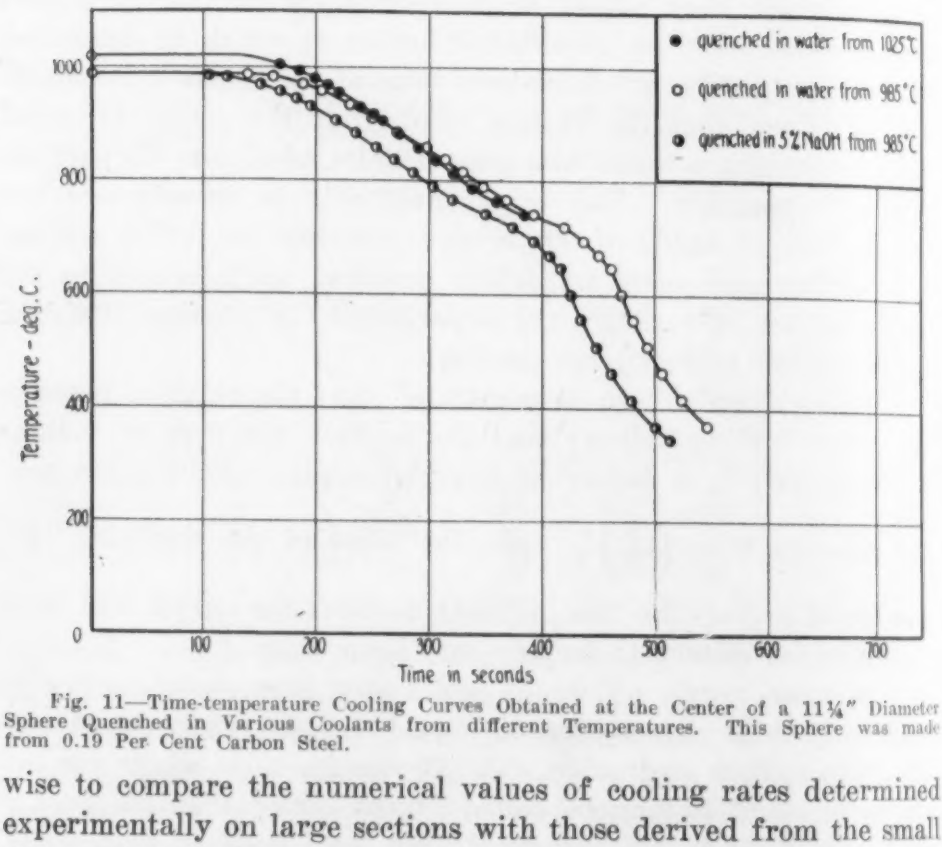


Fig. 11—Time-temperature Cooling Curves Obtained at the Center of a 11¼" Diameter Sphere Quenched in Various Coolants from different Temperatures. This Sphere was made from 0.19 Per Cent Carbon Steel.

change in equipment and methods was desired to check the accuracy of the determinations on the small samples. Special precautions were taken to maintain good contact between the thermocouple and the center of the sphere during both heating and cooling. The thermocouple was mounted on a threaded plug in such a manner that when screwed tightly into the hole bored to the center of the sphere, it pressed the hot junction up against the metal.

Mention has already been made of the fact that the maximum cooling velocity throughout the cooling range is directly proportional, both with respect to its position in the temperature scale and its numerical value to the initial (quenching) temperature (provided the coolant and its temperature are fixed). In both water and 5 per cent sodium hydroxide the maximum velocity is found at about 0.8 of the quenching temperature. This, therefore, offers a simple method of comparison which will be used in discussion of the quenching of the large sphere.

When quenched in water from 1805 degrees Fahr. (985 degrees Cent.) the maximum center cooling velocity was found to be 1.4 degrees Cent. per second (at 790 degrees Cent.); from 1025 degrees Cent. it was 1.5 degrees Cent. per second (at 820 degrees Cent.); quenched in the 5 per cent sodium hydroxide from 985 degrees Cent., it was 1.4 degrees Cent. per second.

Thus the maximum cooling velocity determined directly by experiment at the center of the 11.25 inch diameter sphere was the same when quenched in water as in the 5 per cent sodium hydroxide.

The surface per unit of volume of this sphere is 0.533. From the "mass effect chart" (Fig. 8) or formula (7) the maximum cooling velocity can be computed as in quenching from 875 degrees Cent., it occurs at from 700 to 720 degrees Cent. These values times $\frac{985}{875}$ will then give the respective maximum rates when quenching from 985 degrees Cent. A comparison follows of the derived values with the experimental data.

	Maximum cooling velocity, °C. per sec.	
	Derived value	Experimental value
Quenched from 985° C. into 5% NaOH.	1.35	1.4
Into water	1.40	1.4
Quenched from 1025° C. into water.....	1.52	1.5

An exceedingly close check has been obtained. However, the important feature is that water and 5 per cent sodium hydroxide do not, as in the case of the small samples, give appreciably different center cooling velocities.

It is not, of course, possible from these few experiments to set definite limits within which the "mass effect chart" (Fig. 8) or the hyperbolic curves between center cooling velocity and surface per unit of volume hold good. However, it appears that these curves are valid, within the prescribed limit of accuracy of 5 per cent, at all points until they cross the curve for water, which is represented by the formula

$$V = \left(\frac{S}{W}\right)^{1.75} \times 3.94;$$

subsequently, as the size increases, the velocities in other media appear to approximate those given by water which has been shown to apply for very large masses.

It should now be evident why the exponent "n" of the several formulæ cannot, as previously mentioned in Section IV-2, be used as a direct measure of the "hardening power" of coolants, for in large sections, as clearly shown by the experiments just described, little difference is observed in the center cooling velocity for widely different coolants. In such cases, this is a function of the thermal properties of the metal.

b. Effect of Variation in Composition of Metal Quenched on the Observed Center Cooling Velocity Taken at 720 Degrees Cent.

The described relations and charts have been based on experiments with high carbon steels and cannot be applied directly to metals having widely different thermal properties. A few quenching experiments were carried out to throw light upon the changes in cooling velocity which may be expected when such high carbon steels are replaced by other metals and the results are given in Table V.

The differences in cooling velocity between the high carbon, high carbon-chromium and high speed steels and Armco iron are well within the accuracy of the experiments (5 per cent) but more rapid cooling is obtained in the 32 per cent nickel steel and cop-

per. The described relationships may, therefore, safely be used for carbon steels of varying carbon content (except when thermal transformations alter the cooling rates at 720 degrees Cent.), ball race and high speed steels. Probably they also apply to the low alloy content structural steels. However, attention should be called to the fact that there are much larger differences in the cooling curves in the low temperature ranges. The selected cooling rate at 720 degrees Cent. is taken while the steel is in the austen-

Table V

Cooling Velocity Obtained at 720°C when Quenching ¾" diameter by 3" Cylinders of Various Metals from 875°C into Motionless Water at 20°C

Metal	Cooling velocity at 720° C. in deg. C. per second
0.89% C steel	93
"Armco" iron (about 0.025% C)	97[1]
32% nickel steel	107
High speed steel 13% W; 3.7% Cr; 1.9% V; 0.7% C	92
Bar copper	146

[1]Derived value from experiment with ½" diameter x 2" long cylinder.

itic condition and the carbon in solution; it is, therefore, not related to the variations in thermal conductivity known to exist between steels of varying carbon content at lower temperatures where alpha iron exists.

V. Summary and Conclusions

The results obtained may now be summarized and the following conclusions drawn:

A. Effect of Size and Shape on the Center Cooling Velocity, Taken at 720 Degrees Cent.

1. In quenching steel spheres, rounds and plates, the cooling velocity for any one of these shapes is inversely proportional to some power of the diameter (or thickness) greater than one and less than 2. This power increases generally with the rapidity of the coolant; it is close to 1 for still air (1.15) and approaches 2 in motionless water (1.75) and 5 per cent sodium hydroxide (1.84) at 20 degrees Cent.

2. For a given size the highest cooling velocity is obtained in spheres, an intermediate rate in rounds and the lowest in plates. More specifically, for equal cooling velocity the ratio of the diameter of spheres to the diameter of rounds and thickness of plates

is as 4:3:2, provided the length of the cylinders is 4 times the diameter and the length and width are each 4 times the thickness of the plates. With infinitely long cylinders, and plates having infinite length and width, these ratios are 3:2:1 (directly as the sizes which have equal surface per unit of volume).

3. The cooling time is inversely proportional to the selected cooling velocity provided it is taken over an interval which does not begin or end at a temperature within the range of large heat effects of transformations.

4. The relations between the size and shape of steel quenched and the cooling velocity or time are closely approximated by the following formulæ in which V is the velocity in degrees Cent. per second, T is the time in seconds, D is the stated dimension (diameter or thickness) in inches, S is the surface area in square inches, W is the volume in cubic inches and C, C_1, C_2 and n are constants.

(1) Cooling velocity and diameter or thickness

$$VD^n = C$$

(5) Cooling time and diameter or thickness

$$\frac{T}{D^n} = C_1$$

(6) Cooling time and velocity

$$T = \frac{CC_1}{V}$$

(7) Cooling velocity and surface per unit of volume

$$V = \left(\frac{S}{W}\right)^n \times C_2$$

Values of the several constants were determined for a variety of conditions, but the most useful relation is given by formula (7). From it and the described experiments a "mass-effect" chart was prepared by which it is possible to determine the center cooling velocity, taken at 1330 degrees Fahr. (720 degrees Cent.) of any size of the simple shapes quenched from 1607 degrees Fahr. (875 degrees Cent.) into any coolant, provided this velocity is known for any other size of one of these shapes when quenched from the same temperature into the same coolant. Conversions may be made directly from the chart.

5. The cooling velocity obtained when quenching any of the simple shapes in a given coolant from a definite temperature is a function of the exposed surface per unit of volume. When any two sizes of the simple shapes have equal surfaces per unit of volume their respective center cooling velocities are equal.

B. Effect of Quenching Temperature on the Center Cooling Velocity, Taken at 720 Degrees Cent.

6. Increase in initial temperature when quenching into ordinary oils and water at atmospheric temperatures increases the center cooling velocity. The magnitude of the change is greater for equal temperature rise between 1330 and 1470 degrees Fahr. (720 and 800 degrees Cent.) than above; likewise it is greater in the rapid than in slow coolants but the proportional change is, within the limits of experimental accuracy, the same for the oils as in water.

7. A "quenching temperature-conversion chart" was prepared by which the cooling velocity given by one quenching temperature can be converted into that which would be obtained from any other temperature between 1330 and 1920 degrees Fahr. (720 and 1050 degrees Cent.).

C. General

8. The described relations apply to the simple shapes (spheres, rounds and plates when made of various carbon and some alloy steels) and will give values within about 5 per cent of those determined experimentally. They likewise hold for modifications which do not materially alter the surface per unit of volume of the basic shape which has been modified, but do not apply in those cases in which there is no geometrical center.

9. Since the center cooling velocity, in quenching spheres, rounds and plates, is proportional to some power of the surface per unit of volume, depending upon the coolant used, these relations are represented by a family of hyperbolic curves which, if projected to large enough sizes, will cross. Actually the velocity cannot exceed a certain value which appears to approximate that given by water irrespective of the coolant used. In such cases the rate at which heat is extracted from the center is a function of the thermal properties of the metal and is not affected by differences at the surface, which is small in comparison with the weight or volume and far removed from the center of the mass. The hyperbolic

"mass effect" curves for various coolants, therefore, appear to apply at all points until they cross the curve for water.

10. Within the prescribed limits, the "mass effect" and "temperature conversion charts" prepared will give the center cooling velocity (taken at 720 degrees Cent. when any size of the simple shapes is quenched from any temperature between 1330 and 1920 degrees Fahr. (720 and 1050 degrees Cent.) into the customary oils and aqueous solutions at atmospheric temperatures, provided only this velocity is known when quenching one size and shape from some temperature into the same coolant. The cooling velocity at 720 degrees Cent. was chosen as a basis of comparison, as it had previously been shown to be the best single factor which can be taken from cooling curves to represent the hardening produced in carbon steels.

Acknowledgments

Acknowledgment is made to T. E. Hamill, laboratory assistant, for his assistance in carrying out practically all of the described experiments.

Discussion

D. J. Granger: The author speaks of cooling by air, and in this respect does he mean cooling in the air in the normal temperature, or does he refer to cooling in an air blast.

H. J. French: All of the coolants which we have used are motionless coolants, at ordinary temperature. That means that the air is ordinary air, as in this room. You realize, of course, that there are an unlimited variety of coolants and when I say that, I do not only mean changes in composition, as, for example, from oil to water, but the degree of circulation and the temperature of the bath and other well-known factors all of which influence these rates of cooling. We had necessarily to limit ourselves in experiments of this type to some of the standard coolants in a known condition. We might just as well (and perhaps from some viewpoints, better) taken coolants in motion, because there are certain undesirable effects, even experimentally, when using coolants without circulation; but it forms experimentally a convenient starting point, and those values with the important exponent "n" do not change as much with a change in the circulation, or slight changes in temperature, as they do with change in the chemical composition. The air was motionless, at ordinary temperatures.

Haakon Styri: Mr. French stated that the cooling rates were taken at 720 degrees Cent. in the center. Of course, we are much interested in the hardness of the center, but I think most of us are also interested in the surface hardness. May I ask Mr. French whether he has any experiments showing

what rates of cooling at the surface or near the surface will cause complete hardening (martensitic).

H. J. FRENCH: In answer to your question, Mr. Styri, may I say that we are now working upon the temperature distribution during cooling, including the time-temperature cooling curves at the surface, but we do not at this time have any curves for presentation. We realize the importance of that, as mentioned before, but I would like to call attention to the fact that Mr. Janitzky has made some calculations from our data and some that he has himself, and I believe can compute from these data the cooling curves at the surface. We are planning at the present time, and have actually in progress a study of cooling at the surface and intermediate sections of various sizes and shapes.

Oral Discussion:—By E. J. Janitzky, Illinois Steel Co., Chicago, Illinois.

In scrutinizing the very clear compilation of results obtained by Messrs French and Klopsch and reported in their paper: "Initial Temperature and Mass Effects in Quenching," I found that the curves follow very closely a formula which I derived from observations on air-cooling and which findings were published in the December, 1922, issue of TRANSACTIONS.

The temperature drop in cooling follows according to the formula:

$$t^\circ = \frac{T^\circ}{\left(\frac{T^\circ}{T^\circ_c} - 1\right)\left(\frac{t}{T_c}\right)^n + 1}$$

t° = temperature drop for corresponding time t
T° = temperature from which body was cooled
T°_c = temperature of coolant
T_c = time elapsed until coolant temperature was reached
n = exponent which varies according to coolant, mass and distance from center.

$$\text{In solving,} \quad n = \frac{\log(T^\circ - t^\circ)T_c - \log(T^\circ - T^\circ_c)t^\circ}{\log t - \log T_c}$$

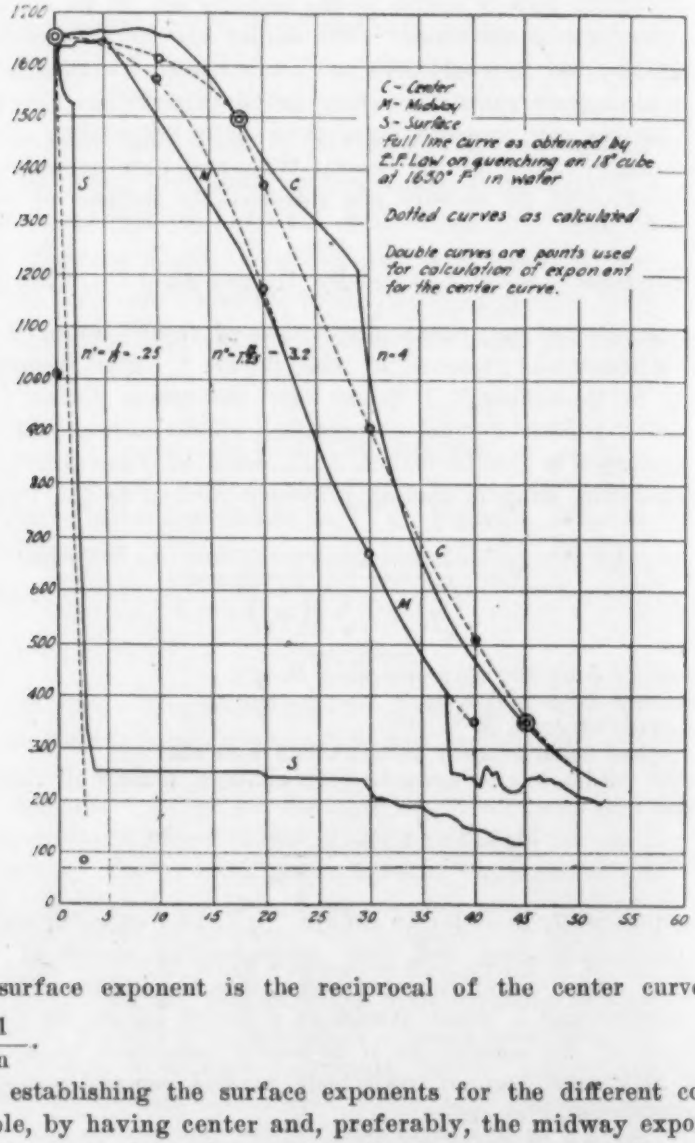
It is obvious that, in order to obtain "n", two experimental observations for temperature drop and their corresponding elapse of time must be obtained, t'° and t' should be obtained before the influence of the transformation range t° and t, which should be observed before the body reaches the temperature of the coolant, as it is nearly impossible to ascertain that point. The total time elapsed until body reaches coolant temperature can be ascertained by the formula:

$$T_c = t \sqrt[n]{\left(\frac{T^\circ}{t^\circ} - 1\right)T^\circ_c}$$

$$n = \frac{\log(T^\circ - t'^\circ)t^\circ - \log(T^\circ - t^\circ)t'^\circ}{\log t' - \log t}$$

Having "n" the exponent of the center curve and the total time required to reach the temperature of the coolant, one is aware that it is nec-

essary to find the exponents for different distances from the center. By comparing Law's (*Iron and Steel Journal*, 1918)—see Fig. 1—curves of surface locations of an 18-inch water-quenched cube, the conclusion is reached



that the surface exponent is the reciprocal of the center curve exponent, namely, $\frac{1}{n}$.

Upon establishing the surface exponents for the different coolants, one will be able, by having center and, preferably, the midway exponent observation at hand, to determine mathematically the exponent for any distance from the center according to the formula given below:

$$n_x = \frac{n}{\left(\frac{n}{n'} - 1\right)\left(\frac{d}{r}\right)^m + 1}$$

$$m = \frac{\log(n - n'')n' - \log(n - n')n''}{\log d - \log r}$$

n_x = exponent sought for any distance from center
n = exponent for center
n′ = exponent for the surface
n″ = exponent preferably midway
d = distance from center
r = radius or thickness when in plate shape.

Obviously, experimental confirmation of the suggestion made in regard to the close approximation of temperature distribution would be another step in the yet dark question. The experiment presented by Mr. French and Mr. Klopsch, though restricted to the center, would be a basis for solving the problem in question on account of its excellence and reliability.

In congratulating the co-authors, I feel that, as members of the Bureau of Standards, they could produce from the splendid work they have developed, factors which would be of considerable value in the study of cooling problems.

Written Discussion:—By Norman B. Pilling, The International Nickel Company, Bayonne, N. J.

The quantitative investigation of the mechanics of quenching is a difficult task, possibly best appreciated by those who have made the attempt. The measurement of cooling velocities of the order of hundreds of degrees Centigrade per second in the interior of a small mass submerged in a liquid is experimentally a hard thing to do, and is especially vulnerable to many concealed errors likely to give grossly misleading results. An independent check upon the experimental technique is, therefore, pertinent. In 1920 the writer made numerous cooling determinations of the type described by Messrs. French and Klopsch at the research laboratory of the Westinghouse Electric and Manufacturing Co., and in searching through some of the data obtained under conditions closely approximating those of the tests described, it was gratifying to find that independently conducted work has led to quantitative agreement in a particlar detail, and to some extent in the general conclusions. The table following gives with such detail as is available comparative measurements of the cooling velocity experienced at the geometrical center of a cylinder ½ inch diameter and 2 inches long.

TABLE I

Observer	Material	Size of Cylinder, Inches	Coolant	Initial Quenching Temp., °C.	Cooling Velocity at 720° C.
					Degrees Cent. per Second
French and Klopsch	0.9 per cent carbon steel	0.5 x 2	Water at 20° Cent.	875	185
Pilling	Nickel + 5 per cent silicon	0.5 x 2	Water at 11° Cent.	830	175

The authors have developed a relation generally inclusive of spheres, cylinders and plates that cooling velocity at 720 degrees Cent. is directly proportional to a variable power "n" of the surface area per unit of mass. This constant "n" has been found to be variable with the nature of the

coolant but not with the shape of the quenched mass, and in general to be larger the more drastic the quenching action of the coolant. In air this approached 1 and was less than 2 for the most drastic quench measured.

The fact that "n" is greater than 1 signifies that under the particular conditions of test the exposed surface becomes relatively less efficient in transferring heat to the cooling medium as the ratio of surface to mass decreases. The writer has found that in at least one condition of relatively fast cooling this constant is consistently equal to unity, in which case cooling velocity is not only a function of the surface per unit of mass but is directly proportional to it. The particular condition referred to is the period of cooling in a vapor jacket which takes place as an initial stage in quenching in rather warm aqueous solutions.[1] The following table gives details of size and surface area reckoned in several different ways, together with the cooling velocity constant "k" for a water bath temperature of 50 degrees Cent. This "k" is that in the equation:

$$\log (T - T_1) = -kt + (T_o - T_1)$$

in which

T = axial temperature
T_o = initial quenching temperature
T_1 = boiling point of quenching bath
t = time.

which has been found experimentally to hold for this stage of cooling.

TABLE II

Cylinder Diameter Millimeters	Weight, Grams	Total Surface (S_t) square centimeters	Cylindrical Surface (S_c) square centimeters	Ratio, Surface to Mass $\frac{S_t}{W}$	$\frac{S_c}{W}$	$\frac{1}{D}$	k
6.45	11.65	10.65	10.32	.914	.888	.155	.077
9.60	29.05	16.08	15.36	.554	.529	.104	.054
12.72	52.95	21.62	20.35	.409	.384	.079	.036
19.07	120.02	33.35	30.50	.278	.254	.052	.025

It is closely related to cooling velocity, in fact, the cooling velocity at any temperature is the product of this constant by the temperature. The values of "n" in the French and Klopsch equation derived from these data are:

Function of Surface per Unit Mass	n
$\frac{S_t}{W}$	0.93
$\frac{S_c}{W}$	0.93
$\frac{1}{D}$	1.04

[1] *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 62, p. 665 (1920). *Physical Review*, 14-222 (1919).

In the experimental case just cited the vapor jacket is thin, in violent agitation and maintained by its very nature at the boiling point at its outer surface, all of which tend to establish a steep temperature gradient through it, improving its heat transmitting power. It is suggested that the constant "n" may approach unity as a limit irrespective of the nature of the coolant when the agitation becomes great enough to prevent a local rise of temperature at the contact with the cooling surface, and that in this sense it might be an indicator of the efficiency of a particular mode of quenching. It is suggestive in this connection to recall the unusual effects produced by quenching in a water jet of high velocity described before the American Society for Testing Materials in 1924.[2] It is to be hoped that the authors will find the opportunity to examine this phase of their subject.

Attention is called to Fig. 11, which differs in character from all the other cooling curves reproduced by the authors in that the curves below 600 degrees Cent. fall well below an extrapolation of the earlier parts of the curve. In this it is suggestive of the type of cooling curve found in warm water quenching, and since the authors have used it as a check on their calculations, a more critical analysis of it would seem in order.

Written Discussion:—By P. E. McKinney, U. S. Naval Gun Factory, Washington, D. C.

The authors of this very interesting paper bring out in graphic form explanations of reactions well known to practical heat treatment men, but seldom appreciated in the light in which they are presented by the authors.

In commercial heat treatment practice the operator has, from practical observation of results obtained, adopted practices which take advantage of the cooling velocity of various quenching media by regulating temperature of quenching and other conditions with a view to obaining cooling reactions which will do the least harm to the finished product.

A point probably not coming directly within the subject of the authors' paper and not touched upon, but of great importance to the steel treater, is the effect of cooling velocity on mechanical stresses which are known to exist in all heat treated objects but in varying degrees, depending upon the methods of heat treatment used. It is more or less an accepted fact that the practice of allowing quenched objects to cool below a temperature of 500 degrees Fahr. in the quenching bath, results in cracking of materials which are inclined to be brittle. From this fact that such cracking can be largely overcome by removing the work from the quenching bath before it has become entirely cold, many observers assume that the damage is done by rapid cooling below 500 degrees Fahr. It is believed that a careful analysis of the phenomena of heat treatment will show that the removal of work from the quenching bath at about 500 degrees Fahr. is a corrective measure to overcome damage already done to the material rather than a preventive measure.

A study of the cooling curves presented by the authors and their application to known results obtained in heat treatment of various classes of material in different quenching media, tend to prove more or less con-

[2] R. H. Smith, *Proceedings*, American Society for Testing Materials, 24, 618 (1924).

clusively that so-called quenching strains are directly related to the cooling velocity just below the critical point of the material. Practical treatment men know that even the most brittle materials may be left in some quenching baths until cold, with entire safety, whereas the same material is almost certain to crack in so-called sharper baths regardless of the temperature of the bath. This is well proven in the case of quenching in mercury.

Figures presented by the authors in Table II show a graduai decrease of difference in cooling velocity between water and oil with increase in cross section. From practical observations, it is believed that this relation may in some instances be entirely reversed as we approach very heavy masses. It does not necessarily follow that reversal of cooling velocity will reverse the relative hardening value of the quenching media as the fall in temperature through the critical range may be sufficiently rapid to maintain its relative position as a hardening agent. The above theory is based on observations made in quenching massive forgings or alloy steels known to be tender under quenching treatment and susceptible to the production of quenching cracks. In the case of such forgings, laboratory data based on small sections, indicates entirely different results from those obtained on heavy sections which are under treatment. It has been noted that the actual results obtained when comparing comparative strengths obtained, the tendency to cracking, etc., on similar material quenched in oil, water and emulsions, shows a wide disparity in the results obtained on the pieces of heavy and light section, the relative position of the three quenching media being in some instances, such as with nickel steel, even reversed.

Some of these differences may be due to variation in surface tension between the object quenched and the quenching media causing massive objects to behave differently than small pieces which are quickly cooled, or to the fact that varying amounts of scale, which is necessarily present with very heavy sections introduce variables, but it is believed that investigation will indicate that the hardening power and quenching velocity below the critical point do not change at the same ratio with increase in mass.

It is believed that additional experiments to study these reactions covering forgings of great mass when treated in the various quenching reagents ranging from brine to oil, would furnish additional interesting and instructive data.

Authors' Closure

It is gratifying that the results presented in this report have been examined in such detail and the authors' hope to be able to follow in future work some of those phases of the general problem touched upon by Messrs. Janitzky and McKinney.

The point raised by Mr. Pilling with respect to Fig. 11 is well taken. Because of the limited equipment available to the authors for quenching large masses, the sphere 11¼ inches in diameter had to be immersed in a limited volume of the coolant. Therefore, the time-temperature cooling curves in Fig. 11 represent cold water quenching in the upper temperature ranges and hot water quenching at the lower temperatures when the large mass of steel had heated the restricted volume of the coolant considerably

Discussion Continued on Page 142

THE CHEMICAL COMPOSITION OF TOOL STEELS

By J. P. Gill and M. A. Frost

Abstract

In this paper the authors have discussed in considerable detail the chemical composition of various types of tool steels. The authors point out that while the chemical composition of a steel is basic, nevertheless the nature of the structure of the steel, as viewed under the microscope, is of much importance.

This paper presents the chemical compositions of many steels which have been analyzed by the authors and also presents the chemical limits used by several manufacturers of tool steel.

The authors state that in their opinion any effort at this time toward the standardization of tool steel specifications by any buyer or organization would be detrimental to the best interests of all.

THE chemical composition of tool steel has not been, as far as the authors know, the subject of an address or a paper before this society. There has even been an apparent tendency to avoid a discussion on this subject, due, probably, to the wide difference of opinion that exists regarding it. During the last several years, greater emphasis has been given to the structure of tool steels, rather than to their composition, and rightly so, since recent improvements in the quality of tool steels have been of structure and not composition. The importance of structure cannot be over-emphasized, and we all well know that two pieces of tool steel may be of the same chemical composition, and one piece good, and the other bad; but if the chemical composition is not right in the beginning, no matter what the final structure, the steel can only serve poorly for the purpose intended.

Chemical composition is basic, yet there is a wide variation between the analyses of the same type steels of different manufacturers. There have been attempts made to standardize the chemical composition of tool steels, but this standardization has gone no further than to draw up some very general specifications for straight carbon and high speed steels. It is probably

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well that this standardization has gone no further, in view of the fact that the uses of tool steels seem to be limitless, and where one analysis may serve best for one operation, a variation from this analysis may serve best for another operation. Also, it should be remembered that alloy and high speed tool steels are young, and that there is a great amount of experimental and research work being done by the tool steel manufacturers for the purpose of bettering their product. Experimental results are daily being put into practice with the result of increasingly better tool steels. To standardize tool steels today would have a tendency to lessen experimental work, and would likely mean the standardization of a product which several years from now we would consider an inferior one. The best tool steel composition for a particular operation will evolve slowly, with the result that standardization, to a certain extent, will take care of itself. Standardization, by its nature, is opposed to change, and if carried to extremes might prove a serious impediment to progress.

There are about 250 different brands of high speed, alloy and carbon tool steels used in this country which have a fairly wide application. There are, probably, from 300 to 600 additional brands that have a limited use. Excepting the carbon tool steels, there is a wide variation in composition between many of these different brands, representing the same general type and recommended for the same purposes. That such a variation as this exists is evidence of disagreement among the manufacturers and users as to what actually constitutes the most desirable composition for the different types. Therefore, it is logical to expect that many of you may disagree with some of the criticisms and comments the authors will make in regard to the chemical composition of some of the more common brands of tool steels. These remarks are based chiefly on personal observation and experience, and their value is merely that of the opinion of the authors.

The simplest type is a straight carbon tool steel and in Tables I and II are given the chemical composition of a number of steels of this type. In Table I are the specifications of several manufacturers, while in Table II are the specifications of a number of users.

Note that in Table I the lowest silicon content is 0.10 per cent and maximum is 0.35 per cent. Silicon is primarily added

to steel as a deoxidizer. In high carbon steels it has an embrittling effect and lessens keenness of edge. This is not noticeable with small amounts and it is doubtful if any material differ-

Table I
Carbon Tool Steels

No.	C	Si	Mn	S	P	Cr	W	Ni
1	not	.10/.25	.20/.30	.02 max.[1]	.02 max.	.....	.....	.....
2	spec.	.10/.30	.20/.35	.035 max.	.035 max.	.....	.....	.....
3	..	.15/.25	.20/.30	.02 max.	.02 max.	.05 max.	.....	.....
4	..	.15/.30	.25/.40	.03 max.	.03 max.	.05 max.	.....	.....
5	..	.20/.35	.10/.30	.03 max.	.03 max.	.05 max.	.05 max.	.05 max.

[1]Max. infers that 00% of this element is desirable.

ence could be noted between 0.10 per cent silicon and 0.30 per cent silicon, although at 0.40 per cent silicon we are undoubtedly approaching the point where these effects become noticeable.

The lowest manganese content is 0.10 per cent and the highest is 0.40. Although manganese in lower and medium carbon steels acts as a toughener, it has an embrittling effect on hardened high carbon steels and also increases the danger of cracking during hardening. A manganese content of 0.30 per cent should represent the maximum, since at 0.45 per cent it is definitely detrimental.

Sulphur and phosphorus vary from a maximum of 0.02 to

Table II
Carbon Tool Steels

Letter	C	Si	Mn	S	P	Cr	Cu	Ni
A	not	.25 max.	.20/.50	.04 max.	.04 max.	.....	.05 max.	.....
B	spec.	.20 max.	.20/.40	.02 max.	.02 max.	.....	.....	.....
C	..	.40/.50	.20/.40	.02 max.	.02 max.	.10/.20	.....	.....
D	..	.15/.25	.20/.35	.025 max.	.025 max.	.10 max.	.....	.....
E	..	.35 max.	.35 max.	.025 max.	.02 max.	.20 max.	.....	.10 max.
F	..	.10/.40	.40 max.	.025 max.	.03 max.	.....	.....	.....

0.035 per cent. It is indeed doubtful if any difference can be noted between 0.02 and 0.035 per cent with either sulphur or phosphorus, but as either passes 0.035 per cent its effect becomes more noticeable. We say it is best to have both these elements as low as possible, yet there is little or no evidence why the restrictions should be more drastic than a maximum of 0.03 per cent.

Chromium and tungsten should be limited to a total of 0.10 per cent in carbon tool steels for many purposes, as either element increases the depth of hardening. This effect, however,

is actually desirable in many cases and one user specifies from 0.10 to 0.30 per cent chromium for one grade of carbon tool steel. The two elements should be held under 0.10 per cent and if a user wishes a greater depth of hardness than obtainable from a straight carbon tool steel, he should specify a light alloy steel.

Only one manufacturer specifies a maximum of nickel and, likewise, only one user, yet nickel is highly detrimental to carbon tool steel—even in small amounts; and it is an element that is today likely to be found in at least small amounts in nearly all steel scrap. A nickel content of 0.20 per cent has a noticeable detrimental effect on a hardened carbon tool steel by causing grain coarseness, which, in turn, imparts brittleness. It is difficult to specify the exact amount above which nickel would be detrimental and below which it would be harmless, but about 0.10 per cent should be the maximum allowable.

One user specifies a maximum of 0.05 per cent copper, very likely because he permits this grade to be made in an open hearth furnace. Copper has an embrittling effect (chiefly hot shortness) on carbon tool steels not noticeable in amounts as small as 0.05 per cent, as do many other elements not likely to be found in straight carbon steels.

Several manufacturers make a carbon tool steel containing from 0.10 to 0.40 per cent vanadium, which is, without question, a better steel than the same steel without the vanadium. The vanadium acts as a toughener and has a noticeable effect upon grain refinement.

In Tables III and IV are the so-called non-deforming, oil hardening steels of the manganese type:

Table III
Non-Deforming, Oil Hardening Steels

No.	C	Mn	Si	S	P	Cr	W	V
1	.85	1.15	.15 max.	.025 max.	.025 max.	.55	..	..
2	.86	1.45	.20 max.	.025 max.	.025 max.	..	..	..
3	.98	.90	.30 max.	.025 max.	.025 max.	.75	..	..
4	.95	1.65	.33 max.	.025 max.	.025 max.	..	..	..
5	.80	1.01	.34 max.	.025 max.	.025 max.	.40	.40	..
6	.90	1.50	.25 max.	.025 max.	.025 max.	..	..	.25
7	.95	1.10	.20 max.	.025 max.	.025 max.	.50	.50	.20

The steels as made by seven different manufacturers are given in Table III. Two of these steels contain chromium and manganese as alloys; two manganese only; one contains man-

ganese and vanadium; one chromium, tungsten and manganese; and one chromium, tungsten, vanadium and manganese. The simplest of these, Nos. 2 and 4, the manganese-carbon, will harden file hard in oil in large sections. Considerable breakage will result in hardening. If the steel is only slightly overheated a coarse grain results. It is the most undesirable of the group. Steel No. 6 has all of the same characteristics except that the 0.25 per cent vanadium tends to prevent grain growth when overheated. Steel No. 1 will show little or no breakage during hardening, and

Table IV
Non-Deforming, Oil Hardening Steels

Letter	C	Si	Mn	S	P	W	Cr	V	Ni
A	.85/1.10	.10/.40	1.00/1.60	.03 max.	.025 max.	.60 max.	.60 max.	.18 max.	.15 max.
B	.85/ .95	.....	.95/1.50	.025 max.	.02 max.	Op.	Op.	Op.	...

will withstand some overheating without grain growth, but it will not harden file hard in oil in large sections due to its low manganese content without sufficient other alloys. Nos. 5 and 7 represent by far the two best types. Either of these will show a minimum of breakage because of low manganese content, will harden file hard in oil because of sufficient tungsten and chromium and will withstand considerable overheating without grain growth. Steel No. 7 will prove a little tougher than No. 5. So far as the non-deforming characteristics of these steels are concerned, any one of them should prove satisfactory.

In Table IV are given two specifications of users of this type steel. Many steels would meet either of these chemical specifications which would be entirely unsatisfactory.

In steels of this type manganese acts as the hardening element, but with the manganese on the high side there results considerable breakage. Therefore, the manganese is lowered and tungsten or chromium, or both, are added. A chromium content of 0.50 per cent alone is insufficient to impart the necessary hardness with a manganese content of approximately 1.00 to 1.20 per cent, and the same is true of 0.50 per cent tungsten. Tungsten is, however, a good hardener and it makes an excellent combination when present with chromium to aid its solution. A small amount of vanadium seems to increase the toughness.

Almost all tool steel manufacturers now make a low-tungsten, high-carbon steel, which replaces in some instances

straight carbon steels; in other instances the manganese non-deforming steels, and in many cases the old finishing steels which were so widely used for finishing cuts and brass turning. In Table V are given several anlyses of this type steel as made by different manufacturers.

This class of steels should not be confused with the steels of similar carbon analyses having a carbon content of about 0.50

Table V
High-Carbon, Low-Tungsten Finishing Steels

No.	C	Si	Mn	S	P	W	Cr	V
1	1.12	.40	.25	.025 max.	.025 max.	1.40	.50	.20
2	1.20	.20	.35	.025 max.	.025 max.	1.65	.50	.25
3	1.00	.19	.26	.025 max.	.025 max.	1.50	..	.12
4	1.00	.14	.12	.025 max.	.025 max.	.60	..	..
5	1.23	.20	.20	.025 max.	.025 max.	2.68	.62	..
6	1.25	.20	.25	.025 max.	.025 max.	1.35	.42	.18
7	1.10	.21	.26	.025 max.	.025 max.	1.05	..	..
8	1.10	.20	.23	.025 max.	.025 max.	2.25	..	..
9	1.15	.30	.20	.025 max.	.025 max.	1.60	.42	.20

per cent which is a punch and chisel steel or with steels having a slightly higher carbon content, with from 2.00 to 5.00 per cent tungsten and used almost exclusively for drawing dies.

An unusual variation exists in this class of steels. Three of these steels, numbers 4, 7 and 8, are tungsten-carbon and the tungsten is only 0.60 per cent in number 4. These three steels would be water hardening and we have found that the hardening is erratic in steels of this type containing tungsten only, nor can they be hardened as hard as the same steels containing a small amount of chromium. Steel number 3 contains tungsten and vanadium and has the same characteristics as the straight tungsten except it is slightly tougher. Five of these steels contain chromium and tungsten and four of these five contain vanadium. Tungsten is more soluble in steel containing chromium than when the chromium is not present; therefore, in these five steels hardening is uniform and they can also be hardened in oil as well as water. When hardened in oil they are non-deforming. These five steels will harden to a greater degree of hardness than the straight tungsten steels. The addition of vanadium tends to prevent segregation and promotes uniformity. As to the tungsten content, from 1.40 to 1.70 per cent seems to be sufficient to give the necessary hardness without undue brittleness. A chromium content of 0.50 per cent also seems sufficient to impart to the

steel the ability to readily and completely dissolve the tungsten. A higher chromium content causes unnecessary brittleness. The best carbon content seems to be about 1.15 per cent and it may be noted that this represents the average carbon content of the nine steels.

Steels of this type will withstand more wear or abrasion than straight carbon steels; they impart a very smooth finishing cut to cast iron, steel or brass and are non-deforming when oil hardened, in which case they are less brittle than the manganese non-deforming steel.

The chemical specification for this type steel is given of one user only in Table VI. His specification is poor, as it represents steels numbers 3 and 7.

The three types of steel so far discussed are all basically cut-

Table VI
High-Carbon, Low-Tungsten Finishing Steels

Letter	C	Si	Mn	S	P	W	Cr	Ni
A	1.15	.35 max.	.30 max.	.025 max.	.025 max.	1.25	.20	.10

ting steels and are used almost wholly in operations involving the cutting and shaping of cold metals. The next group are, as a whole, used for a totally different purpose; that of cutting and

Table VII
Hot Working Die Steels

No.	C	Si	Mn	S	P	W	Cr	V	Ni
A-1	.46	.20	.20	.025 max.	.025 max.	11.00	1.50	..	..
A-2	.33	.30	.20	.025 max.	.025 max.	9.50	3.30	.40	..
A-3	.35	.30	.20	.025 max.	.025 max.	10.50	3.25	.50	..
B-1	.87	.45	.40	.025 max.	.025 max.	....	3.75	..	..
B-2	.90	.20	.40	.025 max.	.025 max.	....	3.25	..	..
B-3	.90	.20	.34	.025 max.	.025 max.	....	4.10	..	..
B-4	.95	30	.20	.025 max.	.025 max.	....	3.90	..	..
C-1	.46	.23	.30	.025 max.	.025 max.	2.25	1.24	.26	..
C-2	.55	.24	.60	.025 max.	.025 max.	....	1.00	.30	..
C-3	.60	.22	.35	.025 max.	.025 max.	1.61	.75	..	..
C-4	.42	.10	.53	.025 max.	.025 max.	....	1.05	..	3.59
C-5	.46	.18	.22	.025 max.	.025 max.	1.02	1.80	..	..
C-6	.50	1.13	.26	.025 max.	.025 max.	1.25	.90	..	..
C-7	.50	.30	.20	.025 max.	.025 max.	2.00	1.65	.25	..

shaping hot metals. This group, which is termed hot-working die steels, divides itself into three general types. Each type has characteristics so different from the others that in most cases they cannot be used interchangeably.

In Table No. VII these three types are listed as A, B and C.

Type "A," the low-carbon high-alloy type, sometimes called a semi-high speed steel, is, of course, oil or air hardening. It cannot be hardened file hard in regular heat treating practice. It will withstand the highest heat of the three types without failure, and also shows the best wearing qualities. It will not withstand a great amount of shock and cannot be cooled in operation with a stream of water without considerable breakage. It is best adapted for hot-forming dies, hot-pressing dies, hot-blanking dies, nut piercers and hot shears. This type of steel has made excellent records for hot-heading dies, but will prove inferior for this work to type "C," due to breakage. It has, likewise, given excellent results in individual instances for gripper dies but again because of breakage it is inferior to type "B" for this class of tools.

Of the three type "A" analyses given, numbers 2 and 3 are practically the same, excepting that number 2 is about 1 per cent lower in tungsten. Number 1 has only 1.50 per cent chromium, compared with 3.25 per cent in numbers 2 and 3. This is not desirable, due to the fact that there is insufficient chromium present to permit an easy solubility of the tungsten. Number 1 steel is also about ten points too high in carbon to give the best results.

Type "B" is the high carbon-chromium type, so widely used for gripper dies in bolt and rivet plants. This type of steel is usually hardened by cooling in air, although oil quenching is, at times, used. Several steel mills furnish this steel in bar length, hardened, ready for use. It will withstand water cooling when in operation much better than type "A" and will also withstand a heavier shock. It serves splendidly for heading round-headed rivets or bolts, but will not withstand the shock resulting from heading square head bolts as well as type "C." There is little choice between the four analyses given, except that number 2 will not harden quite so readily in air as the other three steels; yet, on the other hand, it can be more safely quenched in oil without difficulty from breakage.

The steels listed under type "C" are of the low-carbon, low-alloy type, and although used for hot working, actually have a much wider usage in other fields. Steels of this type are usually hardened by quenching in oil. They are very tough and will withstand a heavy shock without breakage. They can be safely water

cooled in use. In the hot working field they are used for heading square head bolts and for special forging dies. Steels of type "C" are used with probably better all around results than any other type for chisels, punches, heading tools and rivet sets. Numbers 1 and 7 represent the best combination of elements, with sufficient tungsten and chromium to impart hardness and wear and with a 0.25 per cent vanadium content to add toughness and fatigue resistance. Number 2 is too low in alloys to give sufficient hardness. Number 3 is too high in carbon to have the highest degree of toughness. Number 4 is an unusual analysis because of the nickel. Although it performs well, it is inferior to the tungsten-chromium type. Number 6, which contains 1.13 per cent silicon, is comparable to numbers 1 and 7, but does not appear to be quite as tough.

The six general types of carbon and light alloy steels which have been briefly discussed are in general usage and have many applications. There are so many other types that have a more or less limited application or are used as substitutes for some of the types discussed that they cannot, in this short talk, be touched upon even briefly, such as finishing steels, low-tungsten steels, low-chromium steels, chromium-vanadium steels, magnet steels, valve steels, stainless and non-corrosive steels, and special die steels.

Apparently as the application or use of a steel becomes more limited, there is an increasing variation in chemical composition between the steels of that type as made by different manufacturers. To illustrate, Table No. VIII has been compiled of the high-carbon, high-chromium type steel, which is widely used for cold

Table VIII

High-Carbon, High-Chromium Steels

No.	C	Si	Mn	S	P	W	Cr	V	Co	Mn	Ni
1	2.50	.25	.25	...	...	...	11.00	...	...	...	...
2	1.77	.63	.65	.005	.024	9.08	1.43	...	...	...	...
3	2.45	.20	.52	.011	.028	...	13.76	...	...	...	1.05
4	1.67	.35	.18	.008	.039	...	10.40	...	3.01	.61	.93
5	2.50	.06	.49	.013	.018	...	12.78	...	...	...	...
6	1.45	.32	.33	...	...	...	19.40	...	...	...	...
7	2.26	.10	.29	.007	.020	...	13.38	...	...	...	...
8	2.88	..	..	...	...	...	14.80	.50	...	...	...
9	2.06	.32	.14	.027	.011	...	12.29	1.16	...	...	...

drawing dies. All of the steels shown in this table are used and manufactured in this country today.

One other class of steels remains to be discussed, that of high

speed steel. This type of steel, because of its high alloy content and the large number of alloys that may enter into its make-up, permits the widest variation in chemical composition; yet over 95 per cent of all high speed steel used in this country is of the three general types shown in Table No. IX, and of this over 80 per cent is of the 18 per cent tungsten, 4 per cent chromium, 1 per cent vanadium type. In Table X are given a number of high speed steel analyses which do not fall into the three general classes shown in Table No. IX.

Table IX
High Speed Steels

Steel No.	C	Si	Mn	S	P	W	Cr	V	Mo	Co	Cr
A-1	.60/.75	.30	.25	.025 max.	.025 max.	18.50	4.00	.85	...	...	.30
A-2	.60/.75	.30	.25	.025 max.	.025 max.	18.25	4.00	1.00	...	...	..
A-3	.60/.75	.20	.05	.025 max.	.025 max.	17.00	3.20	.70	...	...	..
A-4	.60/.75	.20	.25	.025 max.	.025 max.	18.00	4.20	.60	...	...	..
A-5	.60/.75	.20	.25	.025 max.	.025 max.	17.75	4.00	1.05	...	...	..
A-6	.60/.75	.20	.25	.025 max.	.025 max.	20.25	4.25	1.48	.50	...	..
A-7	.60/.75	.20	.25	.025 max.	.025 max.	18.00	3.15	.85	.24	...	..
A-8	.60/.75	.20	.25	.025 max.	.025 max.	21.00	4.00	1.10	...	...	..
A-9	.60/.75	.20	.25	.025 max.	.025 max.	18.00	4.00	1.00	...	...	..
B-1	.60/.75	.25	.25	.025 max.	.025 max.	13.50	4.00	1.65	...	...	..
B-2	.60/.75	.25	.25	.025 max.	.025 max.	13.75	4.50	1.40	...	...	..
B-3	.60/.75	.25	.25	.025 max.	.025 max.	14.00	4.25	2.05	...	...	..
C-1	.60/.75	.25	.25	.025 max.	.025 max.	17.50	4.00	1.00	...	3.00	..
C-2	.60/.75	.25	.25	.025 max.	.025 max.	17.50	4.00	1.00	...	4.50	..
C-3	.60/.75	.25	.25	.025 max.	.025 max.	17.50	4.00	1.00	.75	4.50	..
C-4	.60/.75	.25	.25	.025 max.	.025 max.	16.00	2.75	.90	1.00	4.00	.20

In both Tables Nos. IX and X, the range of carbon content is listed as the same for all the different steels, since nearly all manufacturers make up their high speed steels purposely with a number of different carbon contents. A certain range of carbons, usually not varying more than three or four points, are grouped together much in the same manner as carbon tool steels are classified according to carbon content. For example, steels with a carbon content from 0.60 to 0.64 per cent would likely be used for chasers and certain classes of blanking dies, from 0.65 to 0.70 per cent carbon for the general run of high speed steel tools, such as milling cutters, drills, reamers, taps, etc., while from 0.70 to 0.75 per cent carbon for lathe and shaper tools, boring tools, tool bits, etc. The steels with the carbon on the low side are noticeably tougher than with carbon on the high side. Also, the lower carbon steels cannot be hardened as hard as the higher carbon. The carbon content in high speed steel is of the utmost importance and often represents the difference between

good and poor performance. The silicon content is usually around 0.25 to 0.30 per cent and there are no detrimental effects noticeable even at 0.40 per cent. Above this the opinion is that it will cause a small amount of brittleness. The manganese is also usually from 0.25 to 0.30 per cent. Over 0.40 per cent there may result brittleness. One manufacturer makes a high speed steel with a manganese content under 0.10 per cent. This offers no apparent advantage.

Table X

High Speed Steels

No.	C	Si	Mn	S	P	W	Cr	V	Co	Mo	Ur
1	.60/.75	.25	.25	.025 max.	.025 max.	13.00	3.75	.35	...	...	..
2	.60/.75	.25	.25	.025 max.	.025 max.	13.00	3.75	1.00	...	...	..
3	.60/.75	.25	.25	.025 max.	.025 max.	18.00	4.00	1.75	...	...	..
4	.60/.75	.25	.25	.025 max.	.025 max.	18.00	4.00	1.75	...	.60	..
5	.60/.75	.25	.25	.025 max.	.025 max.	14.00	2.75	.80	3.50	.90	..
6	.60/.75	.25	.25	.025 max.	.025 max.	14.00	4.25	1.50	...	...	.75

In discussing the tungsten, chromium and vanadium contents, it is assumed that in discussing the variation of one of the elements that the others are average and constant for that type steel.

A tungsten content of 18.00 per cent for type "A" is what most manufacturers desire. This amount has been determined by the observation of many different manufacturers over a period of years. Going above 18.00 per cent tungsten may offer some slight advantage in wearing qualities which is more than offset by increased brittleness. Going below 18.00 per cent lessens the cutting and wearing ability of the steel, although there is some slight increase in toughness. 18.00 per cent then seems to offer the best balance between toughness and wearing ability. As to the chromium content, about 4.00 per cent imparts sufficient hardness both directly and in permitting a greater solubility of the tungsten. Going below 4.00 per cent the steel is less hard so that at 3.00 per cent there is a very noticeable difference. Going above 4.00 per cent causes brittleness which becomes very noticeable at about 5.00 per cent. As to vanadium content, the majority of the manufacturers seem to agree that it is best to work to about 1.00 per cent, but as vanadium is worth some $3.50 per pound there is a tendency to shade this amount and actually add about 0.80 per cent. 1.00 per cent vanadium is better than 0.60 or 0.70

per cent, therefore, the question:—is not 1.50 per cent better than 1.00 per cent? There is indication that it is, but for each ten points of vanadium added above 1.00 per cent much less increased efficiency results than from each ten points below 1.00 per cent; so that going above 1.00 per cent does not increase the efficiency enough to justify the increased cost.

The other elements that are sometimes found in small amounts in type "A" steels are molybdenum and uranium. Molybdenum was first used in some of the old self-hardening steels. It has about the same effect as tungsten except that molybdenum is from two to two and a half times as potent. About 8 per cent molybdenum will, therefore, impart about the same properties to high speed steel as 18 per cent tungsten, except that the molybdenum steel will be tougher. Molybdenum cannot, however, be used in amounts much in excess of 1.00 per cent without causing a surface softness, and this characteristic has prevented its more general use, especially in larger amounts. Uranium seems to offer no advantages in small amounts and if even as little as 0.30 per cent did give some beneficial results, they would be more than offset by the increased dirtiness of the steel resulting from the heavy uranium oxides which remain suspended in the steel and weaken its structure. Therefore, Steel No. 1 would be objectionable because of uranium; Steel No. 2 because it is low in both carbon and vanadium; No. 4 because it is low in vanadium; No. 6 because it is high in tungsten; No. 7 because it is low in chromium; No. 8 because it is high in tungsten; while Nos. 5 and 9 represent the best of the group.

The type of high speed steels designated as type "B" are the so-called low tungsten-high vanadium type, and show little variation except in vanadium. If this type of steel is to compare favorably with the 18-4-1 type, the vanadium content should be above 1.60 per cent. In one of these, Steel No. 2, the vanadium is only 1.40 per cent. As to the relative merits between the 18.00 per cent tungsten, 4.00 per cent chromium, 1.00 per cent vanadium type, and 14.00 per cent tungsten, 4.00 per cent chromium, 2.00 per cent vanadium type, there is considerable difference of opinion. The lower tungsten type can be hardened from a lower temperature, but can be more readily overheated. It is more sensitive to heat treatment. Although the 14-4-2 type has been on the market for some years and is made by a number of dif-

ferent manufacturers, it has made little inroad into replacing the 18-4-1 type.

The cobalt high speed steels designated as type "C," as made by the several manufacturers, contain from 3.00 to 5.00 per cent cobalt and may contain about 1.00 per cent molybdenum and in one steel both molybdenum and uranium. The other elements being the same, 4.50 per cent cobalt is better than 3.00 per cent, but as the cobalt content increases above 5.00 per cent the steel will harden less, so that at some 6.00 or 7.00 per cent cobalt, the steel fails to respond fully to heat treatment. Cobalt seems to increase the temperature at which failure of the cutting edge will take place and also gives better wearing qualities. It slightly increases the brittleness of the steel. Cobalt causes the steel to harden with a soft skin which must be removed before using. Because of this characteristic the steel has been limited in its use to such tools, as lathe, planer, shaper, cut-off and boring tools, which can be ground after hardening. This type steel has proven its worth where it can be used. The addition of small amounts of molybdenum increases its wearing quality. Steel Number 3 would, then, be better than Nos. 1 or 2, while Steel Number 4 is too low in chromium and has uranium.

Table X shows types of high speed steel that have special applications or are of unusual type. Steel No. 1 is used chiefly as a valve steel and has a limited use for such tools as reamers. Steel No. 2 is used for taps and reamers, particularly for taps, since it can be hardened from a lower temperature than an 18-4-1 steel, thereby lessening the tendency to burn or warp the threads. Steel No. 3 is an English steel and Steel No. 4 an American, both made on the basis that if 1.00 per cent vanadium is good for high speed steel 1.75 per cent is better. Steels No. 5 and 6 are quite unusual types in that Steel No. 5 is a low tungsten cobalt steel and that Steel No. 6 is a high vanadium-uranium steel. Neither of these types offers any advantages and either is inferior to the comparable type of the three general types discussed.

Small amounts of arsenic, antimony, tin and copper are likely to be found in high speed steels in varying amounts, as these elements contaminate nearly all foreign tungsten ores. These elements, more particularly arsenic and antimony, cause both hot and cold shortness and are often times the cause of unusual brittleness in high speed steels. The summation of the arsenic, anti-

mony and tin should not exceed about 0.10 per cent, even though it might be difficult to prove that a slightly higher amount than this is detrimental.

In conclusion, we must say that any effort at this time toward the standardization of tool steel specifications by any buyer or organization is detrimental to the best interests of all. Because of the wide range in composition; the satisfactory substitution of one alloy for another; the detrimental effects of small amounts of many elements; the inclusion of oxides and dirt; and the effects of grain size and structure, no purchaser can draw up a specification that would meet commercial practice that would fully protect him from obtaining an undesirable tool steel. The purchaser's best protection is the brand name, as it is the quality mark of the manufacturer. The deserved reputation of a brand is highly prized by the maker and he will in no way jeopardize that reputation by selling an inferior product under that brand name.

No industry, to our knowledge, has been more free in the employment of technical skill than the tool steel manufacturers, yet the making of tool steel is still an art, and this is as true today as it was in the time not long ago when the secrets of the trade were handed down from father to son.

Since the organization of the American Society for Steel Treating, the technical men of the tool steel mills have cooperated with the technical and practical men representing the users to accomplish the purpose set forth in our Society's constitution, which is, to secure cooperation between the practical steel treater and the metallurgist, so that they may understand each other and each benefit thereby to the end that the truth be brought to light.

Without regard to copyright, we will end by saying that "the chief ingredient in tool steel is the honesty and integrity of the maker."

Written Discussion:—By B. H. Delong, Carpenter Steel Co., Reading, Pa.

The writer has read with a great deal of interest the paper entitled "The Chemical Composition of Tool Steels" by J. P. Gill and M. A. Frost, and wishes to congratulate the authors on the very clear and thorough manner with which this subject has been presented.

The fact that there are at present in use, according to the authors' statement, from 550 to 850 brands of carbon and alloy tool steels, all of which have special application, indicate the difficulty of standardization on

the basis of analysis alone. This feature is the result of two factors as follows:

(1) *Variation in Methods of Manufacture of Steel.*—Each individual steel manufacturer has developed through experience, details in processes of manufacture which are characteristic of his product alone. These details are a pronounced factor in giving individual properties to the steel brands regardless of analysis; and, as a result, it is common experience to have steel of the same analysis, but produced by different manufacturers, vary considerably in machinability, proper treatment for certain applications, and tool efficiency. This is an excellent reason for the users to adhere to one brand of steel when it has been found that this particular brand gives satisfactory service under a given set of conditions of shop practice. This does not mean that other analyses of steel or the same analysis made by a different manufacturer may not prove satisfactory or superior with slightly altered changes in tool manufacture or use. It is well, however, for the user to go slowly in making changes of brand, and not to assume that all steels of the same analysis will give equally satisfactory service without change in shop practice.

(2) *Variation in Service Requirements of Tools Performing the Same Class of Work.*—In the same manner as each steel maker develops slight differences in methods of manufacture that have a pronounced effect on the steel, so the makers and users of tools will develop peculiarities which have a pronounced effect upon the service of the tools, and which make it particularly difficult to recommend an analysis or grade of steel which can be depended upon to give the best performance when first introduced. An outstanding example is the use of tool steels in the manufacture of dies for cold heading and upsetting. Some of the factors which influence the service of tools of this character to a marked degree are the depth of impression in the dies, the shape of the impression, the speed at which the upsetting is accomplished, the hardness of the stock being upset, the method of manufacture of the dies, etc. Many of the factors are so important as to require the use of totally different grades of steel, and steels of radically different analyses for the same type of work. These variations are receiving constant attention by the steel maker and by the tool user, but they are so numerous that the only satisfactory method known to the writer to secure the best service is for each user to try the steels out, and vary the type used, and at the same time, the methods of heat treatment and design until the desired results are secured. This naturally calls for close cooperation between the steel maker and the steel user, and this cooperation, which has been greatly furthered by our Society, is very much worth while.

To summarize the above two points, the writer would advise that the only method by which absolutely the best performance upon tools for individual work can be expected is by close cooperation between the steel maker and the steel consumer, and the use of cut and try methods until proper results are attained. This work should not be handicapped by limitations of analysis imposed by the user of the steel for frequently radical changes in analysis have been known to show most gratifying results. The writer has been much pleased to note the increased number of opportunities for

cooperation of this character, and while, perhaps, it does not tend toward standardization of steels according to analysis, it does, without question, tend toward the securing of better tool life and performance, and resulting decreased cost of production on the part of the user of the steel.

With reference to the authors' remarks in reference to the composition of steels, the writer has two thoughts in mind which may prove of interest. These are as follows:

(1) *Sulphur and Phosphorus in Carbon Tool Steels.*—While it has been the writer's observation that the presence of these two harmful ingredients in percentages over 0.02 and 0.03 per cent does not have in itself a detrimental effect upon the performance of steels, it is, nevertheless, his observation that the amount of these ingredients present is a measure of the quality of the raw materials used in the steel manufacture, and also of the care used in the melting operation, both of which are of utmost importance. For this reason, the writer believes that in all high grade carbon tool steels the phosphorus and sulphur should be kept to the lowest commercial limits. It is not at all difficult to produce this material in quantity having a maximum of 0.02 per cent phosphorus and sulphur. The writer is, of course, referring only to carbon steels of the best tool steel quality, and not to the class of carbon steels in which the use of inferior grades of scrap and rapid production methods are essential in order to keep the selling price at the lowest possible figure.

(2) *Non-Deforming Oil Hardening Steels.*—These steels, as described by the authors, are used fundamentally for two reasons as follows:

(a) Tools which will not permit of finished grinding can be machined to size and hardened with practically no distortion or change of shape.

(b) Complicated shaped tools can be successfully hardened in oil without danger of breakage.

The company with which the writer is associated has manufactured for some twenty years a steel of the approximate analysis shown in Table 3, number four. In contradiction to the authors' statements, no trouble has been experienced with steel of this analysis due to breakage in hardening. Steel of this analysis as made by the company referred to is believed superior to others of the same class for the following reasons:

(1) It is readily annealed so as to be cleanly and freely machinable.

(2) It is hardened in oil from approximately the same temperature as that used in water hardening straight carbon steels sometimes used for similar purposes.

(3) It will hold its shape, especially in heavy sections, very accurately during the hardening and drawing operations.

(4) The amount of change of shape in all non-deforming steel is vitally affected by the hardening temperature, and it so happens in steel of the analysis of number four that the proper quenching temperature for maximum hardness and grain refinement is also that which produces the greatest freedom from distortion.

When properly manufactured, steel of this analysis is, to the writer's belief, the most satisfactory of any of the analyses given in Table 3 instead of the most undesirable of the class as stated by the authors.

Written Discussion:—By A. H. Kingsbury, Crucible Steel Company of America, Harrison, N. J.

The authors have dealt with a subject which has a peculiar fascination to the metallurgist, particularly one who is directly connected with the production of steel. As one who has been closely connected with the production, application and heat treatment of tool steels for the past twenty-two years, the writer feels that some of the remarks in this paper are open to constructive criticism.

In reviewing the interesting article, there are what appear to be several points of importance which, on the basis of my own and others' experiences, should not be accepted as facts until they are supported by concrete proof.

The authors' statement in regard to silicon—"in high carbon steels it has an embrittling effect and lessens the keenness of edge"; they state 0.40 per cent silicon as the place at which "we are undoubtedly approaching the point where these effects become noticeable."

For many years at least two well known brands of tool steel, which contain silicon in amounts exceeding 0.40 per cent, have been successfully applied to tools where strong cutting edges are essential.

Messrs. Gill and Frost place the maximum manganese in high carbon tool steels at 0.30 per cent. The fact that several well established brands of tool steels, which have been found to be generally applicable, exceed this point in manganese, indicate that 0.30 per cent manganese does not represent the maximum.

The writer partially agrees with the authors in their remarks regarding the detrimental effect of nickel in appreciable quantities to tool steel. However, on the basis of his own personal observations, cannot agree with them in that its effect is to coarsen the fracture of the steel. The addition of nickel to a carbon steel base lowers its critical, and this fact should be taken into consideration. Thus, if nickel is present in appreciable quantities and its effect of lowering the hardening range in accordance with the percentage present is not observed, the result will be a coarse grained fracture from overheating.

Carefully conducted experiments with a series of tool steels containing varying amounts of nickel up to 1.25 per cent with about 1.00 per cent carbon, has shown an extremely fine grained fracture on hardening, but to obtain this, it was necessary to quench from lower temperatures than normal for steels in which this element was not present in quantities above 0.30 per cent. In fact the steel containing about 1.25 per cent nickel hardened very nicely in 1 inch square sections at a quench of 1300 degrees Fahr., or about 130 degrees below the normal for the same section and composition, without nickel. All pieces gave normal hardness readings. It was found, however, in the case of steels containing nickel over about 0.30 per cent that this element acted to lower the softening or breaking down point on reheating or drawing. This characteristic, along with the possibility of others not discovered, explains the disadvantage of nickel in tool steel.

The authors designate the specification for low tungsten steel in Table 6 as a poor one, as it represents steels Nos. 3 and 7 in Table 5. While I am familiar with the specifications of a number of large consumers of this

type, I do not recognize this specification among them. This specification calls for 0.20 per cent chromium which, as no range is given, likely represents the minimum of the acceptable range to this particular consumer. On the basis of personal acquaintance with steels of this type in production, application, heat treatment, etc., for over a long period, I cannot consistently agree that this specification from a practical point of view is comparable with a steel which does not contain chromium. It is believed that the effects of 0.20 per cent chromium addition to a simple carbon steel are very slight. However, comparisons with and without the addition of chromium to a low tungsten base, seem to indicate quite clearly that the addition of even so small an amount as 0.20 per cent has a much greater effect than one would suspect.

The multitude of complicated variables presented in the modern high speed steels, if one is to judge from the number of publications on the subject, has a great fascination for the constructive or analytical mind. A review of practically the entire bibliography of high speed steel will, if my judgment and experience is a criterion, supply an enormous "kick" to the fascination. Careful and thorough consideration of available publications on the subject of high speed steels as well as personal observations, have convinced me that complications presented by these alloys necessitate proceeding with great caution before drawing definite conclusions as to which one or which set of variables may be the influencing factor in explanation of the reactions which characterize these types of steel. Taylor, in his monumental report, based on years of concentrated study and work, issues a warning as to the danger of drawing definite conclusions until every variable but the one to be determined has been eliminated.

In adding another element, such as cobalt, to the standard high speed steel mix the complications are multiplied. My connection with an organization which has produced a cobalt steel for the past twelve years has supplied data resulting from a number of thorough investigations of such steel. The following comments necessarily relate to Rex AAA and may, therefore, not be applicable to other compositions.

The authors' remarks, that cobalt seems to increase the temperature at which the cutting edge fails, is interpreted to mean that it increases the degree of "red hardness." Comparison of the manner in which a cobalt and non-cobalt tool gutter and fail under as nearly duplicated conditions as possible, seem to effectually contradict this statement. These remarks are not predicated on the results of one observation, but on many duplications. Another observation which appears to strongly support my hypothesis is a comparison between the ratio dry versus lubricated cutting with both a cobalt and non-cobalt steel.

Satisfactory form-tools, in considerable quantities, in various sizes and shapes, have been successfully made from steel containing over 4.00 per cent cobalt. This contradicts the popular conception that cobalt steels necessarily harden with a soft skin. I have personally seen ½ inch square samples of cobalt steel, repeatedly hardened from the open fire, come out file hard on the surface, and the surface after removing the hardening scale by pickling, show Rockwell C hardnesses of 63 to 65.

On certain classes of work the fact seems to be quite firmly established that cobalt tools have much greater durability than the 18, 4 and 1 type. It seems quite safe to state that the relative durability of a tool is a function of (a) its red hardness, (b) natural or abrasion resisting hardness and (c) its "cohesive strength." Note the latter is used to define the resistance of the steel to the breaking or tearing away of small particles from the edge and is not to be confused with "maximum fiber strength" or strength in the aggregate.

On the basis of lengthy research, it appears that cobalt does not increase, in fact probably decreases to an extent the degree of red hardness.

Very careful observations both in the laboratory and in actual work point quite conclusively to the fact that cobalt does not permit of greater natural hardness. Therefore, unless there is some other factor in addition to the three mentioned which affects the durability of the tool, it appears that cobalt has a decided toughening effect, rather than a tendency to slightly embrittle, as stated by Messrs. Gill and Frost.

Authors' Reply

In regard to Mr. Kingsbury's statement concerning the silicon content of carbon tool steels the authors are familiar with several carbon tool steels containing a silicon content higher than 0.40 per cent which are satisfactory to the users. This is not proof that the same steel with a lower silicon content would not do the same work better. The authors do not state that a carbon tool steel with a silicon content higher than 0.40 per cent is not usable or even unsuccessful. They only state the effects of silicon, and when these characteristics become noticeable. The fact that these effects become noticeable in a hardened carbon tool steel at some point slightly above 0.40 per cent should not be interpreted as saying that when these effects become noticeable the steel cannot be used successfully.

Likewise, these same remarks might be applied to manganese. Neither Mr. Kingsbury nor Dr. Mathews has taken exception to the authors' statements regarding the effects of manganese, but seem to differ in what should be the limiting amount, yet neither of them state what in their opinion this should be. We have stated an upper limit of 0.30 per cent for manganese, which may be too low, yet undoubtedly there should be a limiting amount. It is, of course, true that the manganese may vary in somewhat of an inverse ratio to the carbon as stated by Dr. Mathews, and when we stated a limit of 0.30 per cent this should have been limited by stating that it applied to a steel of approximately 1 per cent carbon.

In reference to the low tungsten steels in Tables 5 and 6, Mr. Kingsbury apparently did not read the authors' remarks carefully. The authors plainly state that the steel shown in Table 6 is poor, as it represents steels numbers 3 and 7 of Table 5. Should Mr. Kingsbury have referred to this table he would have found that steels numbers 3 and 7 do not contain chromium, while all of his remarks are based on the assumption that they do contain chromium. We definitely state that a small amount of chromium in this type of steel is very desirable the same as Mr. Kingsbury states.

In regard to cobalt high speed steels it happens that the authors' remarks were confirmed by a large number of laboratory tests and were not based on personal observation alone. Furthermore, these tests were made with several cobalt high speed steels including Rex AAA and the results obtained were similar. The authors state "cobalt seems to increase the temperature at which failure of the cutting edge will take place." Mr. Kingsbury says his observations would contradict this statement. The following simple experiment is one of tests made on which the authors based their statement. A number of samples of several regular 18 per cent tungsten high speed steels and several cobalt high speed steels were each properly hardened. The initial hardness of the cobalt steels was slightly less than of the regular 18 per cent tungsten steels. One sample of each steel was then drawn in lead for one hour at 1100 degrees Fahr. and up to 1400 degrees Fahr. at increments of 50 degrees Fahr. After the 1100 degree Fahr. draw, the cobalt steels were very slightly softer; after the 1150 and 1200 degrees Fahr. draw both steels were of practically the same hardness; after the 1250 degrees Fahr. draw the cobalt steels were harder and with each higher draw the difference between the hardness of the two steels became greater, always with the cobalt steels harder. This experiment certainly indicates that cobalt steels resist softening from high temperatures to a greater degree than an 18 per cent tungsten high speed steel, or in other words cobalt steels have a higher degree of "red hardness."

Cobalt steels do have a tendency to harden with a soft skin or surface, and this softness apparently is the result of partial decarburization. This can be shown by taking two high speed steels, one with and the other without cobalt, and hardening them side by side. Then carefully anneal in a sealed container. Then grind away the scale and remove $\frac{1}{64}$ inch from the outside of each piece and analyze for carbon. It will be found that the outside portion removed from the cobalt steel will show a much lower carbon content than the outside portion removed from the steel without cobalt should the carbon content of both steels have been the same in the beginning.

18 per cent tungsten high speed steels with cobalt, when in a properly hardened condition, are more brittle than the same steel without cobalt when in the same hardened condition. This statement is based on the result of an average of a large number of Izod impact tests and the difference is very definite.

In regard to the comparative hardness between the cobalt and non-cobalt high speed steels, Mr. Kingsbury states, "that cobalt does not permit of greater natural hardness," and in a previous paragraph states "that the relative durability of a tool is a function of (a) its red hardness (b) natural or abrasion resisting hardness." The authors do not clearly understand the meaning of the term "natural hardness." If hardness as shown by the Brinell, Rockwell or Scleroscope is meant, then the authors admit that cobalt steels are slightly softer than non-cobalt steels when both are properly hardened. If resistance to wear (abrasion) is meant then the authors must again make their original statement that "cobalt gives better wearing qualities." Laboratory tests show there is

not a direct relation between hardness (as shown by Brinell, Rockwell or Scleroscope) and wear, also that cobalt high speed steels have better wearing qualities than non-cobalt steels.

Therefore, as Mr. Kingsbury states "the relative durability of a tool is a function of (a) its red hardness (b) natural or abrasion resisting hardness and (c) its 'cohesive strength'," then the results of the authors' investigations show that cobalt high speed steels cut better because (a) they show a greater red hardness (b) show a better wearing quality (abrasive hardness) but that their "cohesive strength" is less than a non-cobalt steel.

In this discussion a cobalt steel means a steel containing from 3.00 to 5.00 per cent cobalt, approximately 0.70 per cent carbon, 18.00 per cent tungsten, 4.00 per cent chromium, 1.00 per cent vanadium with or without a small amount of molybdenum. A non-cobalt steel means a steel containing approximately 0.70 per cent carbon, 18.00 per cent tungsten, 4.00 per cent chromium and 1.00 per cent vanadium.

Written Discussion:—By Jerome Strauss, Naval Gun Factory, Washington

Certain phases of this paper have interested me greatly but before presenting a few questions I should like to comment briefly upon the authors' digression to the problem of standardization. Perhaps the best reply to the issue raised may be made in the form of a quotation from comments of Mr. Albert W. Whitney, chairman of the American Engineering Standards Committee, in replying to an article in the *New York Times* in September, 1923, by Dr. Charles Eliott. Mr. Whitney says, "Standardization cannot be disposed of so summarily. Like any other powerful instrument, it has its dangers; the problem, however, is not how to get rid of it but how to use it." Mr. Whitney further refers to the principal dangers of standardization from which the following two are selected as of most importance in the present case, "too early standardization before the trial stage has been completed . . . . too rigid a standardization that does not allow for . . . . change."

Considering the standardization of tool steels in the light of the first comment, I agree with the authors that most of the low-alloy steels are not yet old enough to warrant standardization. I do, however, feel that carbon tool steels, the high-manganese non-deforming steels, and the high speed steels have been known and used and studied for a sufficiently long period to make standardization of present types possible. In regard to the second issue, I should like to refer to two circumstances. The A. S. T. M. specification B-26-21 for light aluminum alloy castings was proposed as tentative in 1918 and adopted in amended form in 1921. At the present time a revision of this specification is under consideration and of the five original alloys, it is doubtful if more than two alloys will survive; the new specification will presumably have a number of alloys in addition to these two. In the case of the Navy Department specifications, revision is made in accordance with advancement in the arts on the average of once every three years. Surely this does not appear like too rigid standardization, nor does it seem to be throttling research and development. Such work will continue

unquestionably whether specifications and standardization do or do not exist.

The authors must remember that the buyer's only means of describing his needs to the producer is through the medium of a specification and it becomes, perhaps, the most important part of the contract. It makes for a high standard of competition and removes doubt as to what is to be delivered and how the delivered articles are to be examined for compliance with the requirements. Such specifications are in use today by all large consumers and it would seem to be a help to every one when these consumers can agree to like requirements and thereby effect what is known as standardization.

I can frankly say that I have never known cleaner steel even in large sizes than that shipped from the authors' plant and unquestionably the pride of uniform accomplishment is a part of the tool steel mill's creed. But brand name is not always an indication of consistent uniformity. For changes in composition have occurred under the same brand name. And what metallurgist in these days of exacting tool demands and the need for obtaining from each tool the last ounce of service it can render, wants to carry two steels of considerably different composition through the same heat treatment procedure under the assumption that brand name means uniformity?

I am particularly interested in the authors' comments on the ill effects of small amounts of nickel and copper in carbon tool steels and of arsenic, antimony, tin and copper in high speed steels. Can they, perhaps, give some quantitative indications in regard to these harmful effects?

I should like, also, to ask the authors if it has not been their experience that over 1.50 per cent vanadium in an 18.00 per cent tungsten high speed steel does not lower the softening temperature so far as to cause hardening difficulties at the usual hardening temperatures, presumably through its effect upon the melting range.

Authors' Reply

In regard to the ill effects of small amounts of arsenic, antimony, tin and copper in high speed steels, the authors at present are unable to definitely state the relation between these harmful effects and quantity. Usually more than one of these elements are present, and undoubtedly arsenic and antimony are more harmful than either tin or copper, with copper probably the least harmful of the four. Arsenic and antimony seem to make their presence known by first affecting the hot working of the steel by causing hot-shortness. A total amount of 0.12 per cent of arsenic and antimony is noticeable. From inconclusive evidence, tin seems to affect the cutting edge of the tool, while apparently copper must be present in amounts much greater than the other three elements before becoming troublesome.

The authors have noticed that with an 18 per cent tungsten steel, with the other elements constant and raising the vanadium content to 1.50 per cent slightly lowers the proper hardening temperature, insufficient, however, to cause unusual difficulties by using the regular hardening temperature for an 18 per cent tungsten high speed steel.

DR. J. A. MATHEWS: I am very much interested in the paper by Mr. Gill

and his associate and with much of the paper I am in hearty accord. In fact, it has a rather familiar sound. I think I said something on the same order with regard to standardization of specifications last year at Boston. I quoted Dr. Charles W. Eliott's remarks to the effect that standardization has been a distinct detriment to progress in education and along some lines of manufacture.

In reference to the matter of specific analyses, do I understand that your specifications are merely specific analyses of one sample?

J. P. GILL: The majority of them are.

DR. J. A. MATHEWS In that case we are not quite sure that the particular sample in every case represents the standards of the manufacturer. I assure you that all manufacturers have definite standards for their various brands; and not only do they have standards, but I think most of the manufacturers have ideals. In all cases we may not be able to live up to our ideals,—and that is not peculiar to the steel business. The free and easy way in which the authors discuss certain elements and their effects I can hardly agree with.

In connection with Mr. Kingsbury's discussion with regard to silicon, manganese and nickel, I believe it is likely that those steels were developed by different manufacturers, in the first instance, at least, to meet specific problems. One manufacturer's idea of a low tungsten steel may be in connection with threading dies or drop dies or taps or some other line, and the composition may have been based on some specific problem he had to work out. Therefore, I believe that we will have to accept rather cautiously some of those statements in reference to the effect of specific elements, manganese in particular, on which a limit of 0.30 per cent is placed. Manganese, in general, may vary in somewhat of an inverse ratio with the carbon; and it also depends on the purpose for which the tool is to be used, the size of the tool, and some other things desired as to whether 0.30 per cent is the maximum or not.

We are under obligation to Mr. Gill and his associates for a very interesting paper.

A. H. D'ARCAMBAL: The paper just presented by Messrs. Gill and Frost is of very much interest and value to us all, as this subject has never been covered as thoroughly in any paper previously given before the Society. I must thoroughly disagree with the authors' statement, however, that no buyer should purchase tool steel under a specification, but should buy their steel under brand names. For a period of almost fifty years the company with whom the speaker is connected purchased all of their tool steels under brand names, but due to the wide variation in analyses received, wide limits in Brinell hardness, coarse grained structures, etc., that were quite frequently found in the steels so purchased, they found it necessary to draw up specifications covering not only the chemical composition but also the Brinell hardness range, microstructure, fracture, etc., covering the various types of tool steels used.

During the past six years we have been purchasing all of our carbon tool and high speed steels under these specifications, resulting in not only lower manufacturing costs, due to the steel being freer machining and a smaller percentage of the tools cracking in hardening and grinding, but also the producing of tools that have given much longer service in the customers' plants.

The fact that one small tool manufacturer quite often requires tool steels

differently annealed than some other company, due to different methods of manufacture, etc., prove that each large user of tool steel should specify the Brinell limits, etc.

We also have proven by careful tests that a special analysis steel produces a more satisfactory saw, for example, than some standard brand type. This means that we are purchasing a large number of special analysis steels for various types of small tools. We certainly would be taking a step backwards should we decide to use only the so-called "brands" available.

We have found that chromium and nickel each present up to 0.15 per cent do not harm the qualities of plain carbon tool steel. Some manufacturers claim that the chromium and nickel content of their steels is under 0.05 per cent, but we have yet to find such a steel.

The authors stated that carbon tool steel with a silicon content of 0.40 per cent or higher would result in a tool with a lessened keenness of edge. We have found that small tools of certain types made of carbon tool steels containing 0.40 to 0.50 per cent silicon possess a very keen cutting edge.

We agree with the authors that the non-deforming steels containing only carbon and manganese as the hardening elements are very difficult to harden, due to steels of this type possessing a coarse grained structure if only very slightly overheated. The addition of 0.20 to 0.30 per cent vanadium prevents this coarseness of the grain and gives the steel a wide hardening range. Non-deforming steels containing chromium and tungsten also possess a wide hardening range but must be heated to a higher temperature for hardening than the type given in No. 6.

There is still a large tonnage of the low tungsten chromium tool steel being used for cutting tools, but tests have proven that a good quality plain carbon tool steel will make just as good, if not a better, tool than will the low tungsten chromium type. This latter steel is deeper hardening than is the plain carbon tool steel, resulting in tools with a smaller amount of soft core, with resultant lesser toughness.

We were glad to note that the authors went into considerable detail as to the effect of tungsten on high speed steel. So many users of high speed steel believe that if the steel contains a very high percentage of tungsten, the same will make excellent tools, whereas high speed steels with 20% tungsten and higher are not desirable. A large number of the tool steel mills have recently increased the vanadium content of their high speed steel from 0.70 to 1.00 per cent to 1.00 to 1.30 per cent, this being a step in the right direction. The majority of the high speed steel now being manufactured also runs higher in carbon than was formerly the practice.

We find cobalt and molybdenum to be undesirable elements in high speed steel to be used for tools that are not to be ground all over after hardening, due to a soft skin being present after hardening. The cobalt high speed steels have been found to make excellent lathe tools, planer tools and other tools of this type, however, such tools are ground all over before being put into service.

There are a large number of companies in this country purchasing their tool steels under a specification.

OIL BURNING EQUIPMENT FOR INDUSTRIAL FURNACES

By M. H. Mawhinney

Abstract

This paper reviews the installation and operation of oil burning equipment, starting with the storage tank and including the auxiliary equipment. It covers in a general way the chief points of trouble for supplying fuel to the furnace.

The author discusses the correct arrangement of the bricks inside the furnace. He points out that this arrangement must be correct for the satisfactory burning of oil. The principal considerations are: the burner holes, flues and ports, combustion volume and baffles.

The troubles encountered in lighting a cold furnace are discussed and the correct procedure to follow in this operation is given.

The location and remedy of troubles, other than purely mechanical failures, are discussed at some length.

IT is difficult to commence this subject in a paper of this size because of the almost infinite variety of equipment on the market for burning oil and because of the enormous number of applications which may be made of this equipment on the different types of industrial furnaces. For this reason it is advisable to state at the beginning what the paper will cover and then follow this outline without the many possible digressions which would leave only a vague impression of the purpose of the paper. In the first place, it will be assumed that the reader is familiar with the words radiation, convection and conduction, and also with the fundamental principles of heat transfer and application. Then, it will also be assumed that he has had some experience with some type of furnace and the auxiliary equipment, including burners, pumps, blowers, and the rest. With these assumptions, this article will review the installation and operation of this equipment with the purpose of inserting, at as frequent intervals as possible, practical pointers obtained through experience with many different types of installations, and will explain the causes of some of the common troubles experienced.

A paper presented before the Cleveland Convention of the Society, September 14-18, 1925. The author, M. H. Mawhinney, is in the engineering department of the General Furnace Co., Philadelphia.

The logical starting point in considering an oil burning system is the storage tank. Books have been written on storage tanks and contain information on riveted tanks, electric welded tanks, horizontal and vertical tanks, installation of tanks to pass underwriters' specifications in different states, and so on. As this information is available from many sources, it will not be repeated, but attention will be called to the two most frequent mistakes made in various plants, namely, the heating coils and the tank connections.

Steam coils should always be provided in a storage tank to keep the oil warm enough to pump easily. If the coils are too large the heat in excess of that actually required is lost rapidly by radiation from the pipe lines and the oil is evaporated from the surface in the tank in surprisingly large quantities. If the coils are too small, the viscosity of the oil makes it difficult and sometimes impossible to pump from the tank to the furnace. A good arrangement for average conditions consists of four lengths of 1¼-inch pipe the full length of the tank in series and reduced to ½ inch at the inlet and ½ inch or ⅜ inch at the outlet to take off condensation. The heating coils should be located at the bottom of the tank and the outlet should be the lowest point, so that the line will drain itself and prevent freezing.

The tank connections, in addition to the steam inlet and outlet, include oil inlet and outlet and vent pipe. The inlet line through which the tank is filled should always be at least 3 inches when a pump is used in filling, and 4 inches in case it is necessary to depend on gravity. For an unloading pump from the car, an electric rotary pump is ordinarily preferred, simply because the electric wiring is easier to install than steam piping to a steam pump, and because there is less danger of freezing. A rotary pump will never lift over 5 feet, while a safe suction life of 18 feet can be figured with any steam driven pump. The oil outlet is located at the top of the tank and extends down to within not less than 2 inches of the bottom, so that sediment will not be drawn through the delivery pipe. It is a good plan to set the tank slightly higher at the end opposite this connection so that the tank can be completely drained. The size of the delivery line can ordinarily be made the same as the suction inlet of the pump, except in the case of long distances, when the line should be one size larger. It should never be made smaller, regardless of the fact that the pump

may be oversize. The vent pipe should always be made as large as the oil inlet so that a dangerous pressure cannot be built up in the tank in case of overflow.

After leaving the tank, the oil should pass through double strainers which can be easily cleaned, and then into the pump. This pumping system can be either steam or electric, depending upon the layout and policies of the plant. The advantages of either system are of minor importance, the chief arguments in favor of each being that with the steam pump the steam pressure automatically varies with the load on the pump, so that the relief valve is assisted and the action is more sensitive, while the electric system has simpler packing and valves and is easier to take care of. Whatever system is preferred, it should be complete with relief valve, air chamber, and gage. The relief valve should be the same size as the relief connection and should always be piped directly to the tank. It is frequently found that this pipe is connected into the suction line and the operation is always unsatisfactory because any gas or air which has been trapped in the delivery line is carried around indefinitely. The air chamber is absolutely essential in eliminating pulsations and assuring a steady oil pressure to the burners. It is ordinarily supplied with steam systems, and for electric pumps can be made of a piece of 4-inch pipe about 14 inches long, capped at one end and the other end connected to the oil delivery line to the burners by a suitable tee. This delivery line should be of suitable size to supply the required number of burners. The steam gage is important because the oil pressure is a factor in the correct operation of the burners. It should always be protected by a loop in the piping from the line to the gage and this line between the main line and gage should be filled with cylinder oil or some other sulphur-free oil so that the fuel oil in the main line can never get to the inside of the gage. The best fuel oil contains enough sulphur to put an expensive gage out of commission in a few days unless this precaution is observed.

It has been found by tests conducted by the United States Navy that for best atomization in fuel-oil burners, the viscosity of oil should be about 8 on the Engler scale, or about 300 Saybolt seconds. The temperature to which oil must be heated to obtain this viscosity depends on the gravity of the oil, but for any oil lower than 27 Baumé gravity, this temperature must be greater than room temperature. For an average oil of about 18 Baumé

gravity, the temperature required is about 130 degrees Fahr. It is, therefore, advisable in most cases to install an oil heater between the pump and the burners. This heater can be one of many standard types and gives little difficulty.

After supplying the required number of burners, the oil supply line should be continued back to the suction line as a circulating line. This line should be tapped into the suction line between the tank and the pump, and its chief use is to make it possible to circulate the oil and get it hot before the burners are lighted, although it also makes it possible to utilize heated oil which is not used in the first passage instead of returning it to the comparatively cold tank. No relief valves are required in this line except when there is no relief on the pump, but a master valve should be provided after the last burner has been supplied, which can be regulated by hand to assist the relief valve on the pump. For instance, if ten burners are being supplied by the pump and eight are turned out, the master valve should be opened to lengthen the time between operations of the relief valve.

Commercial oil burners are ordinarily designed to operate on high-pressure air or steam from 20 pounds per square inch to 100 pounds per square inch, or on low-pressure air from 4 to 32 ounces per square inch. High-pressure burners are connected to a dry steam line or standard air-compressor. Low-pressure burners require some type of fan or blower. The two chief types are the positive pressure turbo-compressor and the constant volume blower. Each of these types will deliver air satisfactorily to the burner, but each has its advantages. The constant volume blower is cheap but if the demand is reduced, the pressure in the lines will build up to as high as 10 or 15 pounds per square inch and the motor will overheat. This type must, therefore, have a suitable relief valve or hand control and large quantities of air must frequently be wasted when it is not needed. The turbo-blower is more expensive, but as long as the demand does not exceed the capacity of the blower, the pressures will not vary greatly, regardless of the demand. In other words, when the volume required is reduced, the pressure does not build up, as is the case with the constant volume blower. The piping from the blower to the burners can consist of either standard metal pipe or sheet-iron pipe and should contain slide damper blast gates in place of valves for regulation, on account of less friction loss and quicker action. These gates should be far

enough away from the burner that the air can expand and attain the required pressure without excessive velocity when entering the burner. This distance is about 18 inches from the burner. A large blast gate or gate valve should always be in the line at the blower so that the most efficient pressure can be obtained for the burners and this pressure will be the same for all the burners supplied.

Furnace Brickwork

Having covered in a general way the chief points of trouble in the equipment for supplying fuel to the furnace, we now come to the subject of arrangement of brickwork inside the furnace, which must be correct for the satisfactory burning of oil and which is even more difficult to cover in a general way and still give information of value for all forms of furnaces. The principal considerations are the burner hole in the furnace wall, flues and ports, combustion volume, and baffles.

Taking these in the order named, the burner hole is an important factor in the correct operation of the burner. This hole should always flare toward the inside surface of the burner wall, because when made in this way the walls of the burner hole are less apt to interfere with rapid expansion of the atomized oil and air from the burner. The most rapid expansion possible is to be desired when burning oil, because the oil and air are more completely mixed with this condition, and also because the velocity is reduced, which means that the products of combustion are not hurried out of the furnace before they have time to give up the maximum quantity of heat. For all burners which induce air of capacity under 10 gallons of oil per hour, the burner hole should be flared from about 3½ inches diameter at the outside face of the furnace wall to 7 or 8 inches at a point 9 inches from this face. For thicknesses greater than 9 inches, the wall should be spanned with tile and an open combustion space left from this point to the inside of the wall. For burners of the induction type of capacities greater than 10 gallons per hour, the hole should start at 5 inches diameter and flare to 7 or 8 inches diameter in 9 inches thickness. These holes should always be laid up with high temperature cement and made perfectly smooth so as not to obstruct the atomized oil in any way. These holes are made the same for all types of furnaces from the smallest pot furnace to the largest billet heating furnace fired with comparatively small burners.

On small pot furnaces where the walls are possibly only 4½ inches thick, the hole is flared from 3 to 5 inches diameter.

The entire theory of flues is contained in the statement that exactly the same quantity of products of combustion must leave the furnace per unit time through available openings as enter the furnace in that time in the form of air and oil, and that to insure even heating, the location of the flues must be such that the products of combustion reach all parts of the furnace without becoming pocketed in any part. A general idea of the size of flues required is given by the following figures taken from "Industrial Furnaces," by Prof. W. Trinks, which contains complete theory on furnace design, including the theory of location and sizes of flues and ports.

Furnace temperature—degrees Fahr.	1200	1600	2200
Flue area, square inches per square foot hearth area (heating steel)	2.0	3.5	7.3

Flues should always be made as large as possible and covered with suitable bricks or tile to produce satisfactory results. This can only be determined by experiment and the flues must be adjusted by experiment until the pressure in the furnace is just above atmosphere and the flame or hot gases pass evenly over all points in the heating chamber.

The theory of combustion volume can also be found in "Industrial Furnaces" mentioned above, and is especially important in the operation of pot furnaces, rivet-rod and bolt-heating furnaces of small size, and hardening and case hardening furnaces of the underfired type where the combustion chamber is limited. In an industrial furnace, at least 3 cubic feet of combustion space should be available for every gallon of fuel oil which must be burned in the furnace per hour.

The final important consideration in the brickwork arrangement inside a furnace is the baffle wall in front of a furnace burner. This baffle wall should be present in all furnaces of the side-fired or end-fired type, as it is a decided advantage in obtaining better results with any type of burner. An enormous number of furnaces are found in which the burner is fired directly into the chamber which contains the heating material but, in the opinion of the writer, this arrangement is incorrect. The advantages of the bridge wall are that it holds back the flame and insures complete

combustion before the products strike the stock to be heated, and that it helps materially in lighting the burners with a minimum of smoke. The height of the bridge wall should be about 4½ inches above the center line of the burner and the last course should always be laid dry so that if the heat is too confined or the flame thrown too high, the top course can be knocked off without interfering with the operation of the furnace. The distance between the inside of the burner wall and the bridge wall depends on the amount of oil to be burned by each burner and should be about as follows—

Gallons oil per hour	Distance from furnace wall to bridge wall, inches
3	18-24
5	24-30
10	30-42
15	42-60
20	60-84

If the bridge wall is too far from the burner, the temperature behind the wall is not held high enough to help in the atomization and combustion of the oil, while if the wall is too close, it will be burned down in a short time.

Lighting the Furnace

Assuming that the oil equipment and piping has been completed and the brickwork in the furnace arranged according to the above principles, the next consideration is the lighting of the furnace. This is not as easy a thing as it looks in most cases, and without some knowledge of the fundamental facts of oil-burner operation, the first experience is decidedly unpleasant.

The chief source of trouble in lighting up a cold furnace is the effect of the cold surfaces upon combustion. When a mixture of atomized oil and air is ignited and fired into a cold furnace against cold brick and metal surfaces, the temperature of the products of combustion is suddenly reduced, and, as a result, a large percentage of the finely divided carbon particles which have not yet had an opportunity to burn are cooled below the ignition temperature and form dense smoke, or are deposited in the form of soot on the cold surfaces. This difficulty is more pronounced in the case of oil than gas, because the particles are larger and more difficult to burn rapidly. As the brick surfaces become hotter they

offer increasing help in vaporizing the oil. It requires experience to keep the burner lighted until the bricks become hot.

The following procedure should be followed in lighting oil or gas burners:—After placing a lighted ball of waste saturated with carbon oil close to the mouth of the burner,

First—Turn on a slight amount of atomizing air or steam, just sufficient for ignition of a slight amount of fuel.

Second—Allow a slight amount of fuel to enter the furnace, so that a small but steady flame is obtained.

Third—Increase the air and then the fuel a little at a time until the maximum amount of fuel which will burn steadily in the cold chamber is reached. Allow the burner to operate at this point until the bricks become hot, and then gradually increase the air and fuel as fast as the temperature of the bricks will sustain ignition, until full temperature required is reached.

Fourth—Adjust the oil to the required amount, then increase the air supply until smoking just disappears; finally, decrease the air slightly to insure against excess air and oxidizing condition in the furnace.

In most oil burners, atomization is accomplished by air or steam under pressure and the mixed oil and air leave the burner with a velocity which is greater than the speed of ignition of the mixture when not assisted by the vaporizing effect of hot surfaces. For this reason, it is always advisable to place a brick or baffle wall in front of an oil burner, at least while lighting, in order to break up the velocity and afford the air and oil mixture an opportunity to light before passing through the furnace chamber. This arrangement also tends to confine the greatest heat to the brickwork near the burner, causing it to heat faster and accelerate combustion as explained above. If it is not easy to arrange a brick in front of the burner, a sheet metal shield can often be substituted and removed after the burner is started.

It should be remembered in starting an oil burner that unburned combustion gases constitute an extremely effective fire extinguisher, so that if too much oil is turned on at first, the furnace will be filled with cold smoke, and the flame will be smothered. When this happens, as it invariably will at first, the oil should be shut off and the air or steam allowed to blow the gases out of the furnace before again attempting to light the burner. In this connection, it should be remembered that the oil-saturated torch is also producing smoke, so that for small furnaces it is

best to keep this torch small enough to prevent filling the chamber full of smoke before the burner is turned on.

The danger of any serious explosion when lighting an oil burner is not as great as with gas, but some danger is present and care should be used. For that reason, never turn on the oil first, because it will collect in the furnace and when sufficient air has been admitted, an explosion may result. If, however, the air is turned on first so that there is plenty of air available, the oil will ignite as rapidly as admitted.

Before lighting up a "green" furnace which has just been built, it should be thoroughly dried out by means of a wood, coal, or gas fire at low temperature. This removes the moisture in the brick and clay and prevents cracking of the brickwork when heated to high temperature. For large furnaces, this process should last several days but in all cases should continue until steam and moisture is no longer given off by the brickwork.

Location and Remedy of Troubles

It is extremely hazardous to put down cut and dried form rules for the remedy of troubles which are encountered with industrial furnaces and equipment, because each case is a problem in itself, with some different conditions present, and the remedy is almost always a matter of experimental adjustment. The writer will, therefore, attempt to give only practical notes on the faults which he has found to be the commonest sources of trouble.

Neglecting purely mechanical failures, if the oil supply system is installed as outlined in the first part of the paper, the supply of oil to the burners should be entirely satisfactory. The commonest complaint is that the oil pressure fluctuates, which is serious because it is impossible to maintain steady combustion condition in the furnace if the oil varies. This condition can always be eliminated by installation of an air dome to cushion pulsations from the pump. A good gage is a reliable indication of oil pressure, provided the connection between the gage and the line is not too small or throttled by having a partly closed gage cock, in which event the pulsations will not be transmitted to the gage and trouble at the furnace may be attributed to some other cause when it is simply uneven oil supply. In practically all burners the oil supply is regulated by a needle-valve arrangement which can become clogged by dirt and foreign matter in the oil. To

reduce this condition to the minimum, the *oil pressure at the burner should never exceed 8 to 10 pounds.* With this low pressure, the needle-valve will be farther open for a given amount of oil to pass, and as a result, larger pieces of dirt may pass through without clogging. This is important, but is almost always neglected.

The number of different troubles which are experienced with the many different types of industrial furnaces in use is enormous, but the chief causes of complaint are that the furnace will not heat up to the desired temperature or that the furnace is hotter at some points in the chamber than at others. When plenty of fuel is available, both of these conditions are ordinarily due to one or more of the following factors—

Size and location of flues,
Size of combustion space,
Excessive radiation through walls,
Size and number of openings other than flues, and
Arrangement of baffles.

As stated above, the size of the flues in a furnace should be such that with a slight pressure in the furnace, a quantity of flue gases can be removed, which is equivalent to the required amount of fuel entering the furnace. If the flues are too small, the pressure in the furnace will be greater than the small pressure desirable to insure non-oxidizing conditions and the flame and gases will leave through other available doors and cracks, to the discomfort of workmen and to the detriment of the furnace. Also, the flame will be smothered and with induced air burners, their capacity will be reduced, because induction is eliminated by furnace pressure. If the flues are too large, the gases escape before giving up the maximum heat and it is impossible to maintain any pressure in the furnace, so that air is drawn in through every opening, causing oxidation of the stock. The location of the flues must be such that the entire furnace atmosphere is kept moving and that the gases are drawn evenly to all parts of the furnace interior.

The size of the combustion chamber limits the amount of fuel which can be efficiently burned. If the combustion chamber is too small to allow sufficient fuel to be burned to take care of all losses and useful heat, then the furnace will never heat satisfactorily. This is of fundamental importance, but furnaces are frequently

found, especially among the automatic furnaces of recent design, where this is neglected.

Radiation and openings are sources of loss which should be kept as small as possible. A layer of insulation brick will often help in bringing a furnace up to temperature, especially if the area is large and the combustion chamber is limited. All slots and openings must be as small as possible because they are a source of large heat loss and because if they are improperly placed, they interfere with the function of the flues and cause uneven heating. In this connection, where a door must be frequently opened, it is better to keep this door open at all times because every time the door is opened, the conditions in the furnace change and it is impossible to maintain efficient combustion, which is more serious than radiation loss from the door.

Baffles, as explained before, are extremely important, as they determine the amount of heat which will leave the furnace through the flues. If the burner fires against a bridge wall or against the opposite side wall in a narrow furnace, the velocity is broken up and the fuel ignites quickly. This quick ignition causes hot gas to be formed in the shortest possible time, and these gases can travel through the furnace with little velocity and give up the maximum amount of heat to the material. This is especially important with high-pressure burners, but with any type, it frequently happens that a large part of the products of combustion are through the furnace and out of the flues before they have even ignited. The writer is of the opinion that every furnace should be arranged with baffles in front of the burners in spite of the fact that an enormous number of rod heating furnaces, bolt and nut furnaces, rivet forges, and forging furnaces are in use where the burners are fired directly into the furnace with apparently satisfactory results.

It is hoped that some practical suggestions are contained in this paper which will give the operating man some idea of what to look for when things go wrong, as they so frequently do, in the furnace department.

Written Discussion:—By W. M. Hepburn, Surface Combustion Co., N. Y. C.

Mr. Mawhinney has given information which can be of value to steel treaters using oil furnaces. He has departed from the old time custom of dealing in generalities and has not been afraid to deal with specific problems in definite terms.

There are two significant developments on the oil furnace horizon which might well be mentioned at this time:

First, the automatic control of combustion.

Second, the recirculating gasification principle of oil combustion.

Under the first heading, equipment has been developed for the larger furnaces, which in addition to the automatic control of the temperature, controls automatically the composition of the flue gases.

Modification of this type of instrument may soon be expected which will make it practical for the smaller heat treating furnaces. The advantages of the exact automatic control of the furnace atmosphere for heat treating, such as are obtained with the automatic gas fired equipment need no further explanation to the members of this society.

Regarding the recirculating principle of combustion, the hidden value of this feature has been little appreciated in the past. Instead of bridge walls and the resultant destructive zones, it is possible by a venturi throat construction at the burner block, to draw in from the combustion chamber a definite ratio of hot flue gases, which gasify the atomized oil and from there on carry out the combustion and heat distribution in a manner analogous to, we will say, a rich producer gas.

This principle has been applied to furnaces doing extremely fine heat treating work. The temperature uniformity which the proper application of these principles produces, has according to our experience, been far greater than any other type of application. Not only is the intense and destructive temperature of the bridge wall type of combustion zone eliminated due to the softer combustion, but in addition the entraining force of the venturi can be utilized to draw a large portion of the hot gases back to their starting point whcih would otherwise be lost out of the flue. This has the same effect as adding to the length of travel of the gases in the furnace.

The many instances of steel treaters resorting to the most expensive sources of heat is a clear indication that the stage has been passed where the cheapness of B.T.U. will insure the use of any fuel.

The oil furnace manufacturers can be depended upon to meet this challenge for the development, and furnace equipment which are now under way are sufficiently radical to completely change the old order of things.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—PART IV

By H. B. Knowlton

Abstract

This article gives a description of the composition, properties and uses of some of the common types of tool steels. The classification of plain carbon tool steel, according to grade and carbon content, is explained. The responsibilities of the buyer, the tool maker, and the hardener are discussed. A number of alloy steels are described. Purchase and inspection of tool steel are discussed.

Composition, Properties and Uses of Various Tool Steels

THE previous articles[1] of this series have covered the fundamental principles governing annealing, hardening and tempering plain carbon tool steel. In the present article, the composition, properties and uses of some of the common types of tool steels will be discussed.

In order to assure that any tool will give the maximum amount of good service, it is necessary, first of all, that the tool be made of the most suitable steel for the service intended. Similarly, if a tool hardener is to do his hardening and tempering intelligently, it is necessary that he know exactly what steel was used in the manufacture of the tool.

It is unfortunate that at the present time there are many tool makers, tool hardeners, designers, and purchasers of tool steels who are not fully informed concerning the different classes of tool steels. This is not entirely the fault of these men, because in most cases they have not been taught a great deal concerning

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions, the second installment appeared in the June, 1925, issue, and the third installment appeared in the October, 1925, issue.

The author, H. B. Knowlton, member A. S. S. T., is instructor in metallurgy, Milwaukee Vocational School, Milwaukee, Wisconsin.

tool steels. The attention of the writer was recently called to a book on machine shop practice which stated that, so far as the average machinist or tool maker is concerned, there are two kinds of steel: tool steel and machine steel. Such a statement is fully as bad as saying that so far as an employment manager is concerned there are two kinds of men: skilled workers and unskilled workers. Everyone recognizes that a man may be highly skilled at one trade and yet may be of little value in some other trade, but many people do not seem to realize that a certain steel may be excellent for one type of tool, but quite unsatisfactory for another. Most tool makers today recognize several kinds of tool steel, such as high speed, fast-finishing, nondeforming, carbon tool, etc., but their information is frequently not as complete as it should be.

One of the most common errors is the use of the name of the manufacturer as a complete description of a tool steel. For example, it is not uncommon to hear a hardener say that he believes in hardening Sanderson higher (or lower) than Columbia, or some other make. Similarly, it is not uncommon, in some places, for a tool to be sent into the hardening room with the information that it is made of Carpenter, or Bethlehem, or some other make. Such statements are on a par with saying that a certain pair of shoes is made of Walk-Over leather. The men who make such statements evidently do not appreciate that each of the steel companies mentioned make a number of different types of steel, and that there is a greater difference between the different types of steel made by one company than there is between closely competing brands made by different companies.

Another common error, which is equally as bad, is the description of steel as "a good grade of tool steel." Such a description is so vague and indefinite that it means little. Yet there are probably many hardeners who can tell of being called upon to harden tools without any more information than that the tools were made of a good grade of steel. Each tool steel company makes a number of varieties of tool steel, each of which is good for a certain class of work but not so desirable for some other purpose. There is no such thing as a "best kind" of steel for all purposes. If one steel could be made which would be the best for all manner of tools, the work of the tool steel mills would be greatly simplified. To state that a certain variety of steel

is the best without stating for what purpose it is the best, is as bad as stating that a certain variety of medicine is the best for all purposes.

There are many varieties of tool steel on the market. The manufacturers usually designate their steels by brand or trade names. The plain carbon tool steels are usually marked with a number or letter, in addition to the brand name. The Data Sheets in the A. S. S. T. Handbook list 45 manufacturers and agents and about 500 different brands of steel. Even this list does not tell the whole story, for one brand of plain carbon steel may be made in several different carbon contents for different purposes. The Handbook divides the 500 brands into five general classes: plain carbon, special alloy, high speed, nondeforming, and finishing. In some cases the plain carbon steels are subdivided into three classes: special carbon, extra carbon, and regular carbon. Also in the case of many of the alloy steels, the principal element (other than iron and carbon) is mentioned in the table. This is a valuable table, but even it gives only the general classes or types of steel. It should go without saying that all of the steels in any one class are not exactly alike.

It may be well to discuss briefly the different types of tool steels. The largest single constituent of tool steels and all other steels is iron. Even the highest alloy steels contain 65-75 per cent iron. It is also true that all steels contain more or less carbon. The tool steels usually contain from 0.60-1.70 per cent (60-170 points) carbon. All steels also contain certain amounts of manganese, silicon, sulphur, and phosphorus. In the plain carbon tool steels, the amounts of these elements present are low. These steels are called "plain carbon" because carbon is the only, or at least the principal, element added to the iron to give the steel its useful properties. Whenever any other element is intentionally added in large enough proportions to have some commercial effect upon the properties, the steel produced is called an "alloy" steel. The same is true if the manganese or silicon content is intentionally increased to produce special properties. The high speed, special alloy, nondeforming, and finishing types of steel, previously mentioned, are all alloy steels, for they all contain one or more elements other than iron and carbon, which give the steels their particular properties. Some of the steels commonly listed as plain carbon steels are in reality low alloy steels. They are probably

listed as plain carbon steels because, the alloy content being low, the steels are more similar to plain carbon than to the other alloy steels.

Plain Carbon Tool Steels

The term "plain carbon tool steel" is applied to a large family of steels. Some shop men use the term as though it described one particular steel. As a matter of fact, each of the tool steel companies manufactures a number of different kinds of plain carbon tool steel. These vary both in carbon content and in quality.

Quality or Grade

The quality or grade of a plain carbon tool steel should not be confused with the carbon content. By quality or grade is meant the soundness of the steel and the freedom from impurities. Most tool steel companies manufacture three or more grades, or qualities, of plain carbon tool steel. Each of these grades is manufactured with several different carbon contents. If the crucible method be employed in making the steel, the quality of the finished product will depend to a large degree upon the purity of the raw materials that are used. In this method, wrought-iron bars are charged into crucibles together with certain proportions of charcoal and certain fluxes. When the crucibles are heated the iron melts and dissolves the carbon, and the slag rises to the top. Sulphur, phosphorus, silicon, manganese and other impurities are not removed in this method. It is obvious, therefore, that if a pure, high-quality steel is to be made by this method, a pure iron must be used as the raw material. As irons are costly in proportion to their purity, a steel made from an exceptionally pure iron will be higher in price than one made from a less pure iron. The quality of the steel also depends much upon the skill of the melters and mill men, and the care used in the entire process of manufacture. If the steel is made in the electric furnace it is possible to do some refining and removing of impurities. Again the quality of the product will depend upon how much skill is employed in the carrying out of the method. The cost will depend upon the quality of metal produced. It will not be attempted here to discuss which is the better, steel made in the crucible or in the electric furnace. The crucible method is the older, and it is well established that the highest

quality steel may be made by this method. On the other hand many manufacturers claim that an equally high-quality tool steel may be made in the electric furnace if the process is carried out properly. Steel made by the crucible method was first called "cast steel," as this was the first of the steel making methods in which the steel was melted and cast. The term "cast steel" is still used to designate crucible tool steel. Unfortunately, however, in this country it is also sometimes applied to steel made by other methods.

The grades of plain carbon tool steel are usually designated by some brand name. A number of the companies now use the name "SPECIAL" for their first grade, or highest quality, and the name "EXTRA" for the next highest grade. The lower grades are sometimes called "STANDARD," "TOOL ROOM," etc. The steel companies do not all use the same scheme for naming their grades. For particular information concerning the steels of any company it is best to consult their catalog. The highest grade steel may not always be strictly a plain carbon steel. Some of the companies use small amounts of alloys in making their higher grades of so-called "carbon steels."

Carbon Content and Temper Numbers

As has already been stated, each of the grades or qualities of plain carbon tool steel is usually made in several different carbon contents. The price of a crucible tool steel is not affected by the carbon content. It must be remembered that the highest carbon steels seldom contain more than 1.50 per cent of carbon. That is one pound of such a steel will contain 0.015 of a pound (about ¼ ounce) of carbon. Considering that the carbon is added in the form of charcoal, it may be readily seen that the addition of ¼ ounce of carbon could not increase the price of steel as much as one cent per pound. It is true that more charcoal is used than remains as carbon in the finished steel, but allowing for this loss, the cost of charcoal used per pound of finished steel would not affect the price of the latter.

The carbon content does have a decided effect upon the properties of the steel. The higher the carbon content, the greater will be the degree of hardness which can be produced by proper heat treatment. On the other hand the lower the carbon content, the greater will be the toughness of the steel under any given con-

dition of heat treatment. For example, if a 1.30 per cent carbon steel and a 0.70 per cent carbon steel are both hardened and tempered in exactly the same way, the higher carbon steel will be the harder, but the steel with the 0.70 per cent carbon will be the tougher. For this reason the steel companies recommend steels of different carbon contents for making different classes of tools. Files, razors, lathe, planer and shaper tools, when made of plain carbon steel, should be made of a very high carbon steel. These tools all require a high degree of hardness but not a high degree of toughness. On the other hand, tools, such as hammers, cold chisels, and large shear knives, require much greater toughness and resistance to shock, but do not require a high degree of hardness. Consequently they are usually made of steel with less carbon (about 0.80 per cent carbon).

The carbon content of tool steel is sometimes called the "temper." The steel companies make from five to ten different tempers of plain carbon tool steel. The carbon content of each temper is held within a variation of five to ten points (0.05-0.10) per cent. For example, one temper may contain from 1.05 to 1.15 per cent carbon, and the next higher temper contain from 1.15 to 1.25 per cent carbon. Steel with a higher carbon content is usually spoken of as a higher temper, while steel with a lower carbon content is called a lower temper.

The temper, or carbon content, should not be confused with the grade, or quality. It is a common error in the shops to speak of a higher carbon steel as a higher grade. It is true that the highest carbon steels are frequently also high in quality, or grade, and that the lowest carbon tool steels are frequently lower in quality. However, the same grade of steel is usually made in several different tempers. The carbon content, or temper, of a plain carbon tool steel is usually designated by a temper number (letter or symbol). It is customary to stamp plain carbon tool steel bars with both the brand name and the temper number. Many of the steel companies do not inform their customers as to the carbon content of their steels, but nearly all catalogs contain a list of the temper numbers and the uses for which each temper is recommended.

Table I (page 130) shows the temper numbers and letters used by several companies for making steels of different carbon contents. The left hand column gives the carbon content. The next

few columns give the symbols used by different companies. The center column gives the uses for which the steels of the different carbon contents are recommended. The right hand columns show the recommended forging, annealing and hardening temperatures. The extreme right hand column gives the temperatures for normalizing overheated steel. If the steel is in the proper condition when received from the mill, and if it is not subsequently overheated, normalizing should not be necessary.

It has not been attempted in this table to give all of the schemes of marking the different tempers of tool steel. A few examples are selected to show the variations in the marking. The names of the steel companies have been purposely omitted, as it is not desired to mention a few companies to the exclusion of the others. It should also be stated that the table may not be precisely accurate. Some of the steel companies have declined to state what the carbon contents of their different tempers are. It is believed, however, that the table is fairly correct, and it is hoped that it will give the reader some of the general plans of marking plain carbon tool steels. For particular information with regard to the steels made by any company, it is strongly advised that the user carefully study the catalog of that company. The catalogs usually give a list of the tempers with their corresponding marks, and some advice concerning the uses and the proper heat treatment for each temper. The carbon contents are often omitted, but they can be fairly well estimated by the uses for which the different tempers are recommended.

Ordering Plain Carbon Tool Steels

Most of the steel companies prefer that the purchaser should, when ordering plain carbon tool steel, state the purpose for which the steel is to be used. The steel maker then selects the proper grade and temper for the particular use stated. This relieves the purchaser of the responsibility of making the selection. Some buyers, however, neglect to furnish the manufacturers with this information. It is true that the size and shape of the bar ordered are often a safe guide as to the intended use. For example, small octagon bars are usually used for cold chisels, punches and similar tools. Again bars of the proper size and shape for making large die blocks are seldom, if ever, used for other purposes. Consequently, sizes which have only one use are probably made

in one temper only. This will probably apply to a great many sizes and shapes, but it may not apply in every case. The advice to state the use when ordering plain carbon tool steel is certainly quite sound.

Responsibility of the Tool Maker

It is suggested that it would be well for the tool maker to be as well informed as possible concerning the different grades and tempers of plain carbon tool steels, and for him to use the most suitable steel for each purpose. If this is not practicable, he should at least select the steel which is the nearest to the correct grade and quality. Obviously it might be inadvisable to order a special bar of steel to make one single tool. The grade and the temper number are frequently stamped on each bar by the steel maker. Evidently this must be considered important information. Yet some tool makers machine off these marks and thus lose the identity of the steel. The writer feels, from his own experiences in the hardening room, that a much better job of hardening and tempering could be done if the tool maker would in every instance place the description of the steel on a tag accompanying the tools when they are sent to the hardener.

Variation of the Heat Treatment to Suit the Steel

It is also believed that the tool hardener should understand thoroughly the meaning of the grade and temper marks, and that he should know the effect of different hardening and tempering treatments upon the properties of steels of different carbon contents or tempers. With the proper cooperation between the tool maker and the tool hardener, much may be accomplished in the variation of the heat treatment to suit the steel which is readily available. In general, it may be stated that if a tool is made of a steel which is a little too high in carbon, the ordinary hardening and tempering will leave the tool in too brittle a condition. The obvious remedy is to raise the temperature of tempering after hardening. On the other hand, if the steel is a little lower in carbon than usual for the particular tool, it may be well to give the customary hardening treatment, followed by tempering below the usual temperature. There are, however, limits within which these principles may be applied. It would be impossible to make a good razor using a steel of a cold chisel temper, as the steel would not be hard enough, even immediately after quench-

ing without tempering. Similarly it might not be advisable to make cold chisels from steel designed for chilled roll-turning tools. The writer had occasion at one time to harden and temper some machinist's hammers which were made from steel of a drill or edge-tool temper. He found that by raising the drawing temperature to about 125 degrees Fahr. above that ordinarily recommended for tempering hammers, very satisfactory results were obtained. If these hammers had been tempered in the usual way, they would probably have chipped. If sufficient hardness cannot be obtained by the ordinary quenching methods, it is often possible to increase the hardness somewhat by quenching in colder water, in brine, in more rapidly circulating water, or by some other means which will increase the speed of cooling. More rapid cooling may also increase the depth of the hardening. Again it must be remembered that these principles may be applied only within reasonable limits. If the steel is much too low in carbon, sufficient hardness will not be obtained, no matter how fast the quench. The hardener can probably do nothing to compensate for the steel being of a poor quality.

Alloy Tool Steels

In comparatively recent years it has been found that the addition of varying amounts of elements other than iron, carbon and the usual amounts of manganese and silicon, would produce alloy steels with very useful properties. Much experimenting has been done along this line, and there are many different alloy steels on the market, each of which is good for some particular purpose. It will be impossible in this brief article to discuss all of the alloy tool steels, to say nothing of the numerous alloy steels used for other purposes than the manufacture of tools. Furthermore, the alloy tool steels are hard to classify, as the opinions of the manufacturers as to the best composition for a steel for some particular use do not always agree.

Some of the classes of alloy tool steels are quite well known, and it may be well to discuss several of these in a general way. Most of these alloy tool steels are sold under brand names. They are not marked with temper numbers, as each brand is usually made with a certain definite chemical composition, and not with varying carbon contents.

High Speed Tool Steels

The high speed steels are used for tools which take heavy cuts and work at high speeds. Every machinist knows that when tools work under these conditions, their cutting edges become quite hot. Ordinary carbon steel tools lose some of their hardness when they are heated above 400 or 450 degrees Fahr. The particular value of high speed steel tools lies in the fact that they will stand heating up to much higher temperatures without losing their hard cutting edges. In fact some high speed tools will continue to cut while their edges are dull red. For this reason it is possible to use high speed steel tools at higher speeds and take heavier cuts than could possibly be done with plain carbon steel tools. Some people seem to think that high speed steels can be made harder than the other tool steels, but this is not the case. Hardened high speed steel is no harder, if as hard, as some of the other tool steels.

There are several different types of high speed tool steel on the market. Among these may be mentioned the high-tungsten-low-vanadium, the low-tungsten-high-vanadium, and the cobalt high speed steels. The first mentioned of these usually contains 16-18 per cent tungsten, 3-4 per cent chromium, 0.75-1.0 per cent vanadium and 0.60-0.75 per cent carbon. The second class differs from the first in that the tungsten is usually about 13 per cent, while the vanadium is usually raised to about 2 per cent. The cobalt high speed steels are similar to first-mentioned class except that they contain from 2.50-4.0 per cent cobalt in addition to the other elements. Chromium, tungsten, vanadium and cobalt are all metals. When alloyed with iron and carbon in the right proportions, they give the steel produced the peculiar properties of high speed tool steel. For a more detailed discussion of these alloying elements see the A. S. S. T. Handbook.

The figures given above should not be taken as definite limits of chemical composition, as the different steel companies vary somewhat in their formulas. At least one company makes high speed steel containing as high as 19-20 per cent tungsten. It is attempted to give a general idea as to the common types of high speed steel. Besides these there are other high speed steels which do not contain so much of the special alloying elements. They are very good for some purposes, but will not stand as much heat without losing their hardness as the higher alloy high speed steels.

The heat treatment of high speed steel is quite different from that of the plain carbon tool steels. The heat treatment of high speed steel will not be discussed in this article.

Finishing Steels

The finishing steels, as their name implies, are used for finishing tools. Such tools must have hard keen cutting edges. They do not take heavy cuts, but, preferably, should be able to stand running at fairly high speeds. Under these conditions the edges of the finishing tools never become as hot as do the edges of high speed tools used in roughing cuts. Some of the steel companies use the term "fast finishing" for designating this class of steels. The trade name "Double Special" is also often applied to the finishing steels. The A. S. S. T. Handbook gives the following as the typical analysis of finishing steels:

	per cent
Carbon	1.35 to 1.50
Tungsten	3.50 to 5.00
Chromium	0.50 to 1.00
Vanadium	0.20 to 0.30

It will be noted that the same alloys are present as in high speed tool steel, but that the tungsten, chromium and vanadium contents are much lower, and the carbon content is about doubled. As might be expected from the lower alloy and the higher carbon content, these steels can be made harder than high speed steels, but they will not stand as much heating after hardening without losing their hardness. The proper heat treatment for the finishing steels is different from that of either the high speed or the plain carbon tool steels. The A. S. S. T. Handbook recommends an annealing temperature of 1450 to 1525 degrees Fahr., and a hardening temperature of 1475 to 1525 degrees Fahr. Like the plain carbon tool steels, these steels must be quenched in water to attain the maximum hardness. The tempering is similar to the tempering of plain carbon tool steels.

Nondeforming or Oil-Hardening Tool Steels

Dies, taps, and other tools which cannot be ground all over after hardening, and which must pass through the hardening and tempering operations and still come out a very definite size and shape, should be made of an alloy steel especially suited for these requirements. Most of the tool steel mills produce a steel for this particular purpose. These steels are sold under such names

as "Non-Shrink," "Nondeforming," or "Oil-Hardening." In addition they also carry brand names. (For the brand names see the A. S. S. T. Handbook: N 15-24.)

There seems to be a difference of opinion among the manufacturers as to what is the best composition for a nondeforming steel. The A. S. S. T. Handbook gives the following as one of the typical analyses for a nondeforming steel.

	per cent
Carbon	1.00
Manganese	1.00 to 1.25
Chromium	0.50
Tungsten	0.50

The above, however, is not the only formula used in the manufacture of nondeforming steel. Some of the steel companies do not put any chromium or tungsten in their nonshrinking steel. The manganese is frequently 1.50 per cent and sometimes as high as 1.70 per cent. Again, the carbon content may be about 0.85 per cent instead of 1.00 per cent, as given in the above table. Some manufacturers also introduce about 0.20 per cent vanadium into their nondeforming steels.

All of these steels, if properly made and heat treated, may be hardened and tempered without any great change in the final size or shape of the tool. The proper heat treatment will depend upon the exact analysis of the steel. All of the nondeforming steels above mentioned contain 1.00 per cent of manganese, or more, and for this reason they must be quenched in oil in the hardening operation. It is interesting to note that these steels become as hard when quenched in oil as when quenched in water. On the other hand, water quenching makes them brittle and frequently causes cracking.

The steels which contain a relatively high per cent of manganese (1.50 per cent or more) and no tungsten, chromium, or other alloy, may be quenched from temperatures around 1400-1420 degrees Fahr., while the steels containing 0.50 per cent tungsten and 0.50 per cent chromium should be quenched from about 1480-1500 degrees Fahr. If the tungsten content is higher, even a higher quenching temperature may be advantageous. It is claimed for some of the steels containing vanadium that a wider quenching temperature may be used with satisfactory results. From this it should be apparent that, while a number of nondeforming steels may be used with success, the hardener should know the

particular characteristics of each steel he has to harden, if he is to produce the best results. It is not sufficient for the hardener to be informed that a tool is made of a nonshrinking or oil-hardening tool steel.

Pneumatic Chisel Steels

Another interesting type of alloy tool steel is that used for pneumatic chisels. These tools present a somewhat different problem than that of the ordinary blacksmith or hand chisel. The latter type of chisel is usually hardened on the cutting end only, the remainder of the chisel being left soft. If a pneumatic chisel were hardened and tempered in the same manner, the blunt end of the chisel would soon become battered into the shape of a mushroom and would stick in the barrel of the pneumatic tool. The requirements for these chisels are, that the cutting edges be quite hard and that the whole chisel be fairly hard and very tough. To meet these rather drastic requirements, the steel companies have brought out a number of special alloy steels for pneumatic chisels. The composition of these steels vary somewhat. In the main they contain 0.50-0.65 per cent carbon and 0.50-2.00 per cent tungsten. They may or may not contain small amounts of chromium and vanadium. The hardening treatment for a chisel made of the 2 per cent tungsten steel consists in heating the whole chisel to 1600 degrees Fahr. and quenching all over in oil. After this they may be drawn all over in oil or melted saltpeter. After this treatment they will excel the ordinary carbon steel chisels in a hard cutting test, and at the same time they are so tough that it is difficult to break them with a sledge.

Hot Work Steels

There are a number of special alloy steels on the market, which are recommended for gripping dies, heading dies, punches, shears and similar tools which work on hot steel. In general all of these tools must withstand considerable heat and retain a considerable degree of hardness. At the same time they all require some toughness. However, there is some difference between the service conditions which are met by the different tools in this class. For example, the gripping dies probably have to withstand more heat than do the heading dies but they do not require as much toughness. Some of the steel companies make several different hot work steels for the different types of tools in this class.

The following are two of the types of hot work steels mentioned in the A. S. S. T. Handbook:

	I per cent	II per cent
Carbon	0.30- 0.45	0.30-0.55
Tungsten	8.00-11.00	1.50-2.50
Chromium	2.50- 3.50	1.25-2.00
Vanadium	3.30- 0.60	0.15-0.40

The first mentioned of these will probably have greater heat resisting properties, while the latter should have greater toughness and shock resistance. These are not the only types of heat resisting steels. Some of the hot work steels do not contain any tungsten but get their special properties from chromium or chromium and vanadium. The heat treatment of hot work tools will depend upon the particular steel used.

Die Blocks

Large die blocks are frequently made of special alloy steels. As die blocks are larger than most tools, they do not cool as rapidly during quenching as do the smaller tools. Furthermore, the center of the block does not cool as rapidly as the surface. The result is that when a plain carbon steel is used, the surface is hardened by quenching, but the hardness does not penetrate very deep, because the deeper portions of the block do not cool rapidly enough to produce the maximum hardness. Then, too, plain carbon steel dies must be quenched in water to produce the necessary hardness. Large die blocks are usually quenched face down, with the face, only a very few inches at the most, below the surface of the water, and the rest of the die held out of the water. This treatment, while it leaves the bulk of the die in a relatively soft, tough condition, sets up great strains, due to the great difference in the cooling speeds in different parts of the block.

Some of the alloy die steels will harden with a much slower speed of cooling. They may be quenched all over in oil, and will harden deeper in from the surface without the great difference in the speed of cooling in different parts of the block. Among the alloys used in making die steels may be mentioned nickel, chromium, and vanadium. Nickel is a well known toughener, and chromium and vanadium give oil-hardening properties.

High-Chromium Cobalt Steel for Dies

One of the interesting tool steels brought out in recent years

is the high-chromium cobalt steel. This steel contains about 12 per cent chromium, and 3-4 per cent cobalt, with a carbon content over 1.50 per cent. It may also contain small amounts of other alloying elements. It is peculiar in that it has a relatively fine structure as cast. It can be annealed to produce suitable machinability and, after proper hardening, has great resistance to wear. It is different from high speed and many other alloy steels in that it does not require forging to bring out its useful properties. Consequently, this steel may be, and is, cast to the approximate shape of the final tool. It is an air-hardening steel. It is recommended for dies and certain other classes of tools.

Stainless Steel

Stainless steel is another high-chromium steel which gets its name and its principal uses from the fact that it does not readily rust or corrode. It is very useful for cutlery, and surgical instruments and other tools which are exposed to conditions which tend to cause corrosion. It should be remarked that after this steel is forged, the scale must be thoroughly removed or it will not be stainless. This steel is usually lower in carbon than most tool steels and does not have the hardness of many of the other types of tool steels.

Low Tungsten Steel for Cutting Tools

Steels containing about 1.00 to 1.30 per cent carbon and 1.50 to 2.00 per cent tungsten, and sometimes containing from 0.50 to 1.00 per cent chromium and 0-0.25 per cent vanadium, are sometimes used for keen-edged tools, such as milling cutters and taps. Tools made from these steels should be hardened by quenching in water from about 1450-1475 degrees Fahr. The tempering is similar to that of the plain carbon steels.

Other Special Alloy Steels

It is not claimed that this is a complete or exhaustive treatise on alloy tool steels. There are many special steels for special purposes. It has been attempted to describe briefly some of the common types. Special steels for hack saws, wood working tools, magnets, valves, etc., have not been discussed. It should also be mentioned that there are some steels which are commonly classed as plain carbon tool steels which really contain small amounts of alloys.

It is hoped that this discussion will give the reader a general idea of the different classes of alloy tool steels. It might be well for the users of tool steel to consult several reputable steel companies for their advice in the selection of the best kind of steel for their particular jobs.

General Remarks on the Effect of Alloys

Chromium combines with the carbon and tends to increase the hardening power without increasing the brittleness proportionately. The higher chromium steels resist corrosion. Chromium steels require higher hardening temperatures, but do not require as fast cooling speeds in order to procure the maximum hardness. The highest chromium steels are air hardening and many of the others are oil hardening. After hardening, the chromium steels will stand more or less heat without losing their hardness, depending upon the amount of the alloy present. Chromium is frequently used in combination with other alloys.

Tungsten is probably best known for its power of making steel heat resisting. It also increases the hardening power of the carbon. When tungsten is used with some other alloy, the latter is usually chromium. They seem to intensify the action of each other. The use of chromium and tungsten in high speed and hot work steels has already been discussed. Tungsten is also used in permanent magnets and valves. Just as the tungsten makes the hardness more permanent even when the steel is heated, it also makes the magnets more permanent. In the lower tungsten steels the alloy probably serves principally as a hardener. Tungsten steels in general must be heated to higher temperatures for hardening, but do not have to be cooled so rapidly to produce hardness. The higher the tungsten content, the greater are both of these effects.

Vanadium is used usually with one or more other alloys. It combines with the carbon, and alloys with the iron as well. Vanadium helps to rid the steel of harmful gases, and thus increases the soundess of the steel. The chromium-vanadium steels used in automotive steels seldom contain more than 0.25 per cent vanadium, while the chromium is usually around 1 per cent. In tool steels the vanadium is frequently higher, reaching 1-2 per cent or more. Vanadium not only acts as a scavenger, but in combination with chromium and other metals increases the depth

of hardening and the strength of the steel without a corresponding decrease in the toughness. Like chromium and tungsten, vanadium also raises the hardening temperature.

Manganese is present in large or small quantities in nearly all steels. However, steels are not classed as manganese alloy steels unless the manganese content is much higher than in the ordinary "plain carbon steels." The low and medium carbon steels may contain from 0.40 to 0.80 per cent manganese without being considered alloy steels. The plain carbon tool steels seldom contain over 0.25 per cent manganese. The oil hardening alloy tool steels containing 1.0 to 1.5 per cent manganese have already been mentioned. Small amounts of manganese serve as cleaners and also combine with the sulphur, making it somewhat less harmful. Larger amounts of manganese lower the critical point and increase the hardening power but also increase the brittleness. The steels containing from 1.00 to 2.00 per cent manganese are usually quenched in oil instead of water to avoid producing brittleness. Steels containing from 2.00 to 7.00 per cent manganese and no other alloy are very brittle and are not used. High manganese steels containing about 12 per cent manganese and 1.25 per cent carbon are quite hard and are tough at the same time. They are used for railroad switch points, cross-overs, ore-crushing machinery and some other purposes.

Silicon is another excellent scavenger, but is not found in any considerable quantities in most tool steels. It dissolves in the iron but does not combine with the carbon. One-half of one per cent or more of silicon in a high carbon tool steel may tend to prevent the iron from combining with the carbon and, consequently prevent, in some degree, the hardening of the steel. Silicon, together with manganese or chromium, has been used successfully in high carbon steels. Both manganese and chromium combine with carbon in spite of the action of the silicon. Some of the tool steels are said to contain 0.50 per cent silicon and 0.25 per cent chromium. The writer has handled some light armor plate which also contained silicon as one of the alloys. The use of silicon together with manganese in making spring steel is well known. The silicon-manganese spring steels fall out of the tool steel range. They usually contain from 0.45 to 0.65 per cent carbon; 0.50 to 0.80 per cent manganese; and 1.50 to 2.10 per cent silicon.

Molybdenum is somewhat similar to tungsten. It was once used in large proportions in making high speed tool steel, but this practice has been largely, if not entirely, discontinued. On the other hand, steels containing about 0.25 per cent molybdenum and about 1.00 per cent chromium have become quite popular in recent years, particularly the chromium-molybdenum steels containing low or medium carbon contents.

Nickel is not usually used in tool steels. Both the high and low nickel steels are used for other purposes. Nickel up to 5 per cent is used in low and medium carbon steels. It increases strength and toughness but not the hardening power. The high nickel steels, containing over 27 per cent nickel, have some interesting uses due to their great toughness, rust and corrosion resistance, and low coefficient of expansion with change of temperature. These steels will not be discussed in detail at this time.

Sulphur and phophorus are objectionable impurities and tend to produce brittleness. Consequently the content of these impurities should be kept as low as practicable in all steels. In the better grades of low and medium carbon steels the sulphur and phosphorus are held below 0.050 per cent and 0.045 per cent respectively. In tool steels the percentage of these impurities is often much lower than these figures.

Cobalt is probably similar in its action to nickel, but works better in high carbon steels than the latter metal does. Its use in cobalt high speed and high chromium cobalt steels has already been mentioned.

The elements thus far mentioned are not the only ones used in the production of alloy steels. Copper, zirconium, titanium, uranium, and probably other elements, may be used to advantage in the manufacture of alloy steels for certain special purposes.

Purchasing Tool Steel Under Specifications or by Brand

In the foregoing discussion it has been attempted to give the reader some conception of the composition, properties and uses of some of the common types of tool steels. It may be noted, however, that definite limits for the chemical composition of the different types of steel have not been stated. Also, in cases where different types of steel are recommended for the same purpose, the writer has avoided the statement of a preference for one type over the others. Discussion of the relative merits of the crucible

and the electric furnace methods of manufacture have also been avoided. It has been the intent to make this article generally descriptive of some of the common types of tool steel on the market and to avoid discussion of points which may be under dispute. Furthermore, it has not been attempted to discuss all of the types of tool steel. It is hoped rather to arouse the interest of the reader in the subject and encourage him to study the different tool steels and determine which ones are the best suited for his particular uses. This may be best accomplished by co-operating with the mills manufacturing tool steel.

It is a much disputed question whether the user should purchase tool steels under definite specifications or buy only under brand names. Some of the steel companies insist that the user should never impose any specifications upon the manufacturer. They prefer to have the user state the purpose for which the steel is to be used and trust implicitly in the manufacturer to furnish the best steel for the job. Under these conditions the steel companies are usually willing to guarantee performance. On the other hand one of the leading manufacturers has stated that when the user places any specification whatsoever on the steel, he should absolve the manufacturer from any responsibility for the performance of the steel. On the other side of the argument, we find statements from some of the largest users of tool steel that they have much better results when they purchase under specifications and purchase from reliable manufacturers as well.

There is probably something to be said on both sides of this argument. Certainly nothing could be more dangerous than the purchase of tool steel on the open market under chemical specifications only. It cannot be too emphatically stated that as much, or more, depends upon the skill and care employed in manufacture, as upon the chemical composition. Furthermore, it is difficult to give a specification which will fully describe a tool steel without resorting to such vague terms "well made," "high quality," etc. The inspection of incoming steel is an equally difficult task. The writer remembers all too well his experience for a U. S. Arsenal which was compelled by law to advertise for bids and accept the low bidder or give a sufficient reason for rejection. The final test should be a practical service test. However, such tests are long and expensive. While these tests may be useful in making the initial selection of a brand of tool steel, it is not

Table I

Showing Carbon Content, Temper Numbers, Uses and Temperatures for Forging, Annealing and Hardening

Carbon Content Per Cent	Carbon Content and Temper Number Manufacturer or Dealer*								Uses TYPICAL ANALYSIS Carbon .....As stated Manganese ..... .15-.30 Sulphur .....Under .03 Phosphorus .....Under .03 Silicon .....Under .30	Temperatures Degrees F. for Annealing		
	A	B	C	D	E	F	G	H		Forging	and Hardening	Normalizing
1.65	...	..	...	...	..	...	...	7		....	....	....
1.60	...	16	...	...	..	...	...	7		....	....	....
1.55	...	16	...	...	..	...	...	7		....	....	....
1.50	...	15	...	...	1	...	...	7	Tools requiring extreme hardness: roll corrugating, chilled roll, turning.		1375 to 1425	1875 to 1925
1.45	...	15	...	...	1	...	7	7				
1.40	6½	14	...	...	..	1	7	7	Roll corrugating, chilled roll turning, graver tools.	1440 to 1470	1375 to 1425	1800 to 1850
1.35	6½	14	6	XII	..	1	6½	7				
1.30	6	13	...	XII	..	1½	6½	6½	Lathe, planer, and slotter tools; brass working tools, drawing dies, razors.	1440 to 1470	1375 to 1425	1725 to 1775
1.25	5½	13	5½	XI	2	1½	6	6½				
1.20	5	12	5	XI	2	2	6	6	Small taps; trimming and cutting dies; threading dies; circular cutters; forming and boring tools; twist drills; large lathe, planer and slotter tools; woodworking tools; ball races, peening hammers, granite points; edge tools in general.	1450 to 1500	1375 to 1425	1650 to 1700
1.15	5	12	5	X	3	2	5½	6				
1.10	4½	11	...	X	3	2½	5½	5½	Milling cutters; taps; trimming dies; reamers; saw swages; circular cutters; mill picks; woodworking; threading dies; granite tools.	1500 to 1550	1375 to 1425	1575 to 1625
1.05	4½	11	4½	IX	..	2½	5	5½				
1.00	4	10	4	IX	4	3	5	5	Taps, reamers; mining drills; channeling drills; large milling cutters; punches; axes; cups and cones.	1500 to 1550	1375 to 1425	1500 to 1550
.95	3½	10	4	VIII	4	3	4½	5				
.90	3½	9	3½	VIII	..	3½	4½	4½	Punches; large cutting and trimming dies; drop dies for cold work; mining drills; small shear knives; hand chisels; arbors.	1500 to 1550	1380 to 1440	
.85	3	9	3½	VII	5	3½	4	4				
.80	3	8	3	VII	5	4	4	4	Large shear knives; punches; chisels; hammers; sledges; cold sets track chisels; forging dies; hammer dies; boiler makers' tools.	1600 to 1650	1400 to 1456	
.75	2½	8	...	VI	..	4	3½	3½				
.70	2	7	2½	VI	..	4½	3½	3½	Track tools; smith shop tools; rivet sets; cupping tools; hot drop forging dies.	1600 to 1700	1425 to 1475	
.65	2	7	...	V	..	4½	3	...				

*Letters have been substituted for manufacturer's or dealer's name

usually feasible to make such tests the routine procedure in the inspection of all incoming shipments.

On the other hand the writer cannot believe that the chemical composition, the hardness, and the microstructure, have nothing to do with the properties and usefulness of the steel. As already mentioned, some of the largest users of tool steel have found it advisable to impose specifications and to inspect all incoming shipments. The composition, hardness and microstructure may not tell the whole story concerning tool steel, but they certainly tell a very important and essential part of the story. It is hard to understand why wide variations in analysis may not make a difference in the properties of the steel. The following are given as examples of some of the rejections the writer has had occasion to make:

Type of Steel: Non-Deforming. Label .....

	Carbon per cent	Manganese per cent
Usual Analysis	0.80-0.90	1.30-1.50
Analysis of the shipment which was rejected..	1.16	0.26
	1.19	0.26
	1.18	0.26

Type of Steel: Carbon, 2nd quality. Label .....Extra .....

	Carbon per cent
Usual Analysis	0.75-0.80
Analysis of the rejected steel (average from 3 samples)	0.65

Both of the lots above mentioned, which were off in chemical composition, were received from a well known steel company which is very insistent in its statement that the buyer should never pay any attention to the chemical analysis. The writer cannot see how either of these steels could have functioned in the same manner as steels of the usual compositions. This is not to be taken as a criticism of the steel company (which has not been named) but is cited to show that even the best steel companies may at times make mistakes. It is true that most of the steel received from the better manufacturers is satisfactory, but should not the buyer be allowed to protect himself against the occasional mistakes? There are many other examples beside the ones given. Tool steel has been received with the sulphur as high as 0.08 per cent. During the war it was not uncommon to find wide varia-

tions in the tungsten content of the same brand of high speed tool steel. (This was true particularly with certain brands.)

With regard to the steel companies' statement that they guarantee performance, and that the buyer should not complain until the steel actually fails in service, it seems rather obvious that it is highly desirable to reject the steel which is going to fail in service before the damage is actually done. It recalls the old question as to whether there should be a fence at the top of the hill or a hospital at the bottom.

The inspection of incoming tool steel for micro-structure and hardness will not be discussed here. This point was touched on in the last article of this series, which described the annealing of tool steel. It has also been rather thoroughly investigated by Emmons, d'Arcambal and others.

The following is suggested as a procedure which should be satisfactory with the user and the manufacturer of tool steel: In selecting tool steel for any job, the user should get the best advice from several reputable steel companies, and then try out the several brands recommended under practical conditions, selecting the one which gives the best service. The brand selected should be analyzed, examined under the microscope, and should be tested for hardness and fracture. The steel company should be asked to furnish steel which is similar to the sample tested within reasonable limits of variation.

For the benefit of some of the smaller users of tool steel who could not afford to conduct long, expensive tests, nor to employ routine chemical and microscopic checking of all incoming steel, let it be said that the best steel companies are probably right about 98-99 per cent of the time. Where there is a large volume of business, the saving of the other one or two per cent is well worth the cost of the inspection.

TRACING MATERIALS THROUGH PRODUCTION

By J. E. Nelson

Abstract

The method here outlined has been in use for several years at the plant of the Barber-Colman Company. Each bar is given a number and a metallurgical test, after which a report card is filled out and returned to the stock room, where it is filed. A record of the bar is also kept in the laboratory. When the work has left the heat treating department the record is filed, giving the history of the parts while in the department. Should any difficulty be encountered during the process of manufacture or in service, a reference can always be made to the history of the original bar.

IN industrial plants where metallurgical and chemical laboratories are maintained to check up the quality of incoming material, particularly steel, it is quite important that a system be adopted for tracing the material through to the finished product. It is also important that a record be kept after the part has left the plant in case some difficulty is encountered in its use.

The method herein outlined has been in use for several years at the plant of the Barber-Colman Company and has proved to be quite successful.

As a shipment of steel is received each bar is given a number. A disk one quarter of an inch thick is cut from bars 1 inch and over in diameter. For bars under 1 inch diameter a piece 2 inches long is taken. This disk is given the same number as the bar and is sent to the laboratory with a report card giving the number, size and grade of the material.

Where it is possible to obtain bars or billets with heat numbers, it is customary to make a chemical analysis on a certain percentage of the total number of bars, but each bar is given a metallurgical test.

The disks are first given the deep-etch test in hot hydrochloric acid (1 part water, 1 part hydrochloric acid) and examined for dirt, segregation, cracks and porosity. They are then tested for hardness with the Brinell machine, drilled and hardened.

In the case of high speed steel the samples are hardened and

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broken. After examining the fracture and inspecting for seams and cracks, a sample is polished for microscopic examination. Carbide segregation gives the steel maker and user the greatest concern. When badly segregated in the ingot, subsequent forging, even though carried on to a great extent, does not entirely eliminate its bad effect. The carbides should be well broken up, the size of the stringers and nests are governed by the size of the bar,

F252 5-14-18 6M LABORATORY RECORD | DATE REC'D | FINISHED

CLASS OF STEEL
BAR NO: SIZE: | TEMPER: | GRADE:

SPECIFICATION:	C	S	P	Si	Mn	Cr	W	V	Ni
ANALYSIS:									

HEAT TREATMENT:	ANNEAL	CARBON	REFI'G	HARD'G	TEMP'G
APPLIED ○ / RECOM'D ○					

INSPECT	FRACTURE	SCLER	BRINELL

Fig. 1—Laboratory Record Card Used in Tabulating the History of Tests. This Card is 3 Inches Wide and 5 Inches Long and is Printed on White Cardboard.

and good judgment must be used to determine just how thin these stringers should be and what is possible to be obtained from the best mill practice.

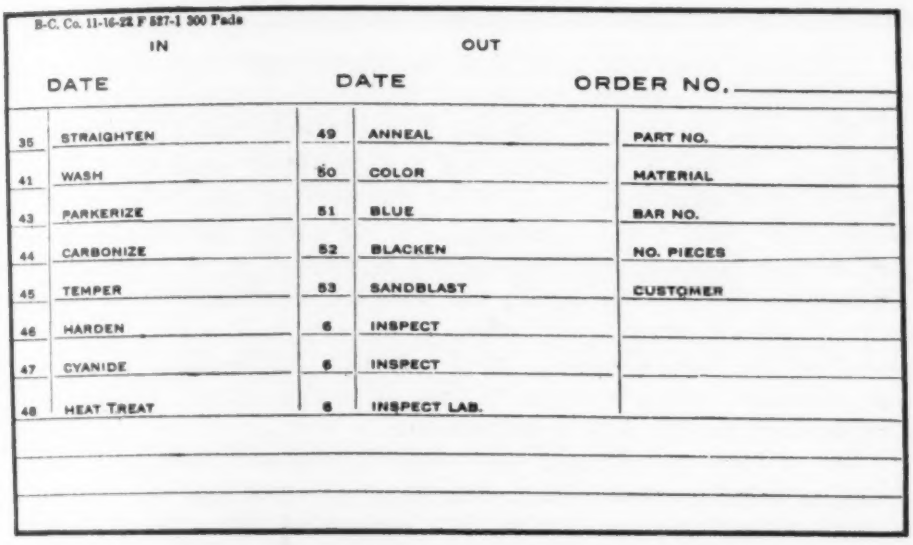
Carbon tool steel and oil hardening steels are examined in a soft condition for microstructure. The best all-round structure we have found is granular pearlite (spheroidal cementite) with not more than 20 per cent lamellar pearlite. The samples are then hardened, broken and examined for fracture, cracks, seams and the extent of the decarburized surface.

The report card is filled out and returned to the stock room where it is filed. The laboratory also keeps a record of the bar. Fig. 1 shows the type of card that is used.

When orders for material are filled by the steel stock department the bar number and grade are noted on the route card which accompanies the parts (Fig. 2). This card accompanies the work through the plant, and when it reaches the heat treating department

a record is made showing the kind of tool, size, name of customer, heat treatment and bar number. We use records of three colors, that is, red for high speed, yellow for carbon tool steel, and white for carburizing work.

When the work has left the heat treating department the


B-C. Co. 11-16-22 F 827-1 300 Pads

IN DATE		OUT DATE		ORDER NO.
35	STRAIGHTEN	49	ANNEAL	PART NO.
41	WASH	50	COLOR	MATERIAL
43	PARKERIZE	51	BLUE	BAR NO.
44	CARBONIZE	52	BLACKEN	NO. PIECES
45	TEMPER	53	SANDBLAST	CUSTOMER
46	HARDEN	6	INSPECT	
47	CYANIDE	6	INSPECT	
48	HEAT TREAT	6	INSPECT LAB.	

Fig. 2—Route Card Which Accompanies Work Through the Factory. This Card is 4 Inches Wide and 6 Inches Long and is Printed on Three Differently Colored Cards. Red, for High Speed Steel; Yellow for Carbon Tool Steel; and White for Carburizing Work.

record is filed, giving the history of the parts while in the heat treating department.

Should any difficulty be encountered during the process of manufacture, a reference can always be made to the history of the original bar. Should the part be returned for any reason, a ready reference may be made to the records showing the history of the part in the heat treating department and to the material from which the part was produced.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

MAKING SPRINGS FOR MOTOR VEHICLES. By Arthur Murphy, associate editor, in *Canadian Machinery*, November 12, 1925, page 15.

The author of this paper discusses the benefits that have come to the manufacture of springs in the motor car industry from metallurgical research. Springs today stand four or five times the work of those a few years ago, because the "skill" and "guessing" of the forger has been replaced by heat treating furnaces, with temperatures maintained at the proper degree by pyrometers. The Dowsley Spring and Axle Co., Chatham, Ont., a subsidiary of the Ontario Products Co., is taken as an example of a thoroughly modern plant, and its work discussed. There are 145 men employed in this plant and production averages about 55 tons of springs a day, a single spring weighing anywhere from 17 to 44 pounds.

The plant is so arranged that material follows a straight path from storage to shipping room. Until a few years ago all springs were heat treated in small oil-fired furnaces. Today this method has been discarded. A continuous heat treating, forming, and quenching process has been evolved, which is practically automatic and eliminates the human element. As an example of what careful heat treatment has done toward prolonging the life of springs, the results of tests of springs made by the hand method and those by the continuous heat treatment method, are interesting. Some years ago 40,000 deflections were about the average before failure, now 120,000 is a low figure.

PERMANENT-MOLD ALUMINUM CASTINGS AND THEIR FIELD OF USEFULNESS. By J. B. Chaffe Jr., The Permold Co., in *American Machinist*, November 5, 1925, page 743.

This article is an abstract of a paper presented at the meeting of the American Foundrymen's Association at Syracuse, N. Y., October 5-9, 1925. The problems discussed are: the overcoming of shrinkage, venting, advantages of the permanent-mold process, and applications of three types of aluminum-alloy castings. In order to avoid shrinkage, the molds are designed so that there is a progressive freezing from the furthest points of the castings to the gates, and the gates and sprues are the last part to solidify. For venting in permanent molding special arrangements must be made to get rid of the air in the mold cavity. Some advantages of the permanent-mold casting are: freedom from blow holes and porosity; dense, homogeneous and fine grain structure; greater strength, greater elongation and greater resistance to impact; relative accuracy in dimensions; smooth, bright surfaces. Until 1912 all aluminum-casting production was done by the sand-casting process, but other methods, using metal molds, are gradually taking business away from the sand foundries.

DIFFERENCES IN OPEN-HEARTH BOILS. By H. D. Hibbard, consulting metallurgical engineer, Plainfield, N. J., in *Iron Age*, December 3, 1925, page 1511.

In discussing this subject the writer classifies open-hearth boils according to degree and violence, taking into consideration uses and character of ten recognized types. He states the necessity of not confounding the gases of liquid steel with those of hot solid steel, or with those of cold steel. The action designated as boil is the escape from the bath of bubbles of gas, chiefly carbonic oxide, which is generated by the oxidation of carbon in the metal. The boil is important because it gives more information than anything else as to the concentration of uncombined or free oxide of iron in the slag. Causes of boil are considered, also ways of moderating the boil, and effects of boil. Open-hearth boils are divided into ten divisions: dead bath, almost dead bath, incipient boil, gentle boil, moderate boil, brisk boil, strong boil, jet boil, strong jet boil, and Talbot reaction. A boil which does not seem to belong to any of the classes into which the subject is divided, is called an in-between boil.

Two succeeding articles on this subject will consider each degree of boil and its significance, and particular cases.

IMPACT VALUES OF A NICKEL STEEL. By F. T. Sisco, metallurgist engineering division, air service, McCook Field, Dayton, Ohio, in *Iron Age*, December 3, 1925, page 1513.

In this article the writer considers the impact value of a nickel steel that is quenched at a temperature lower than usual. Material and methods of testing are discussed, a table of the composition of the material used is given, and also a schedule of the heat treatment. Illustrations of steel quenched at different degrees are shown. A table is also given which summarizes the results of the tests made and the conclusions drawn.

HIGH TEMPERATURES HURT RIVETS. By A. L. Spencer, Jr., Pittsburgh Screw & Bolt Co., Pittsburgh, in *Iron Age*, December 3, 1925, page 1521.

This article is from a paper delivered at the third annual convention of the American Institute of Steel Construction, White Sulphur Springs, W. Va., November 11-14. The writer gives the results of an investigation of complaints on breakage of rivets made at seven different shops. Two outstanding conditions causing breakage were: high-heating furnace temperatures and riveting stresses. In making these tests, four types of heating were employed, coal or coke forges, electric heaters, and gas forges. Two grades of steel were used, A. S. M. E. boiler grade and high-sulphur cut-thread bolt grade. Conclusions were drawn that high temperatures cause rivets to break in hammer driving, or, at least, destroy the physical properties to such an extent as to render rivets unfit for service. For each grade of rivet steel there is a "critical" temperature for driving which must not be exceeded, and this temperature increases consistently with the manganese content within the range covered by the investigation. Another conclusion was that high sulphur, accompanied by high managnese, was not a cause of rivets breaking in driving.

MAKING HIGH-GRADE STEEL. By John A. Coyle, consulting engineer, Pittsburgh, in *Iron Trade Review*, December 10, 1925, page 1457.

In this article the writer discusses the methods used in America and Great Britain in making crucible steel. British steel-makers use crucibles of clay, which permit closer control of carbon in the ingots than do graphite crucibles, which are used by many American crucible steel manufacturers. The latter are not as breakable as clay crucibles, hold a heavier charge uniformly, and less man power is used in their handling. An analysis of American and German graphite pots is given.

The writer considers making high-grade steel an art rather than a science, the different steps of the process demanding a skill and judgment that makes the manufacturer of such steel an artist of high degree.

METALLURGY OWES MUCH TO FRANCE. By Sir Robert Hadfield, British metallurgist, in *Iron Trade Review*, December 3, 1925, page 1398.

The writer tells of the early experimenters, scientists and writers who helped to lay the foundation for modern industry in France. Among the early French metallurgists were Reaumur, Gabriel Jars, who gives an interesting account of the methods originally practiced in Sheffield, England, Vauquelin and P. Berthier. Carnot is another French scientist whose investigations in thermodynamics are the basis of modern practice in many metallurgical processes. The contributions of these and other (not mentioned) French scientists have been of the greatest importance, and the world is greatly indebted to France because of their work.

TEN TYPES OF OPEN-HEARTH BOILS. By H. D. Hibbard, consulting metallurgical engineer, Plainfield, N. J., in *Iron Age*, December 10, 1925, page 1605.

This is the second part of an article on open-hearth boils. The first part appeared December 3, page 1511. The first part divided boils into ten classes. These are discussed in detail in this section and in the conclusion of the article. Five divisions are considered in the part of the article appearing in this issue, as follows: dead bath, almost dead bath, incipient boil, gently boil, moderate boil.

BETA IRON AND THE SPECIFIC HEATS OF PURE IRON. An abridged translation by A. Papineau-Couture of an article by A. Brodsky in *Revue de Metallurgie*, May, 1925, in *Iron Age*, December 10, 1925, page 1645.

The writer states that the existence of beta iron has not been proved, in spite of the work which has been devoted to the solution of the problem. A formula has been deduced by the writer by means of which he was able to calculate the specific heat of pure iron from zero degree absolute to its melting point. These formulas have been shown to be accurate and to agree with experimental results even at temperatures 1000 degrees below that which served as a starting point, and it is quite safe to apply them to higher temperatures, right up to the melting point of iron.

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,559,963, **Treatment of Copper Alloys, Friedrich Heusler, Dillenburg, Germany, Assignor to the Firm of Isabellenhuette Gesellschaft Mit Beschraenkter Haftung, Dillenburg, Germany.**

This patent describes a method of increasing the hardness of copper alloys containing small proportions of manganese and aluminum, by subjecting the alloys, after they have been cast, rolled, or forged, to a prolonged heat treatment at a temperature of approximately 200 to 250 degrees Cent. Such an alloy, when heated for thirty-six hours at 230 degrees Cent. had its tensile strength increased by 2 per cent, and other desirable advantages imparted to it.

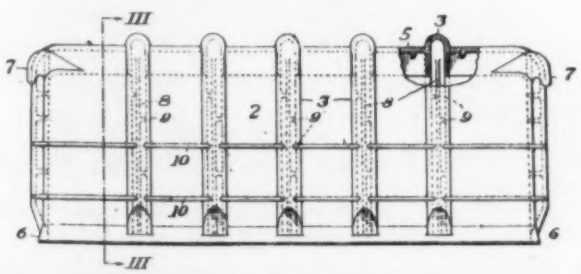
1,560,335, **Process of Improving Alloys and Metals, Johann Czochralski, Frankfort-on-the-Main, Germany, Assignor to American Lurgi Corporation, New York, a Corporation.**

This patent discussed at some length the advantages of individual grains or single large crystals of metal in the industrial fields, and points out a method whereby a single crystal of any desired size can be produced.

The process comprises cold working the metal structure and then maintaining it for an extended period of time at a relatively lower recrystallization temperature favorable to nucleus formation, then raising the crystallization temperature at a relatively high rate and maintaining the temperature until conversion into a single crystal structure is complete.

1,560,708, **Annealing Box, Frederick E. Mesta, West Homestead, Pennsylvania, Assignor to Mesta Machine Company, Pittsburgh, Pennsylvania, a Corporation of Pennsylvania.**

This patent relates to a cast annealing box 5 which is reinforced

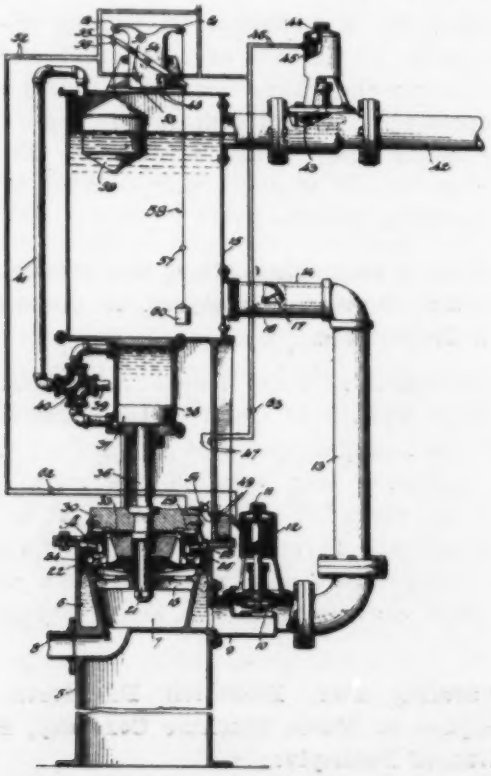


against distortion and breakage by means of corrugations 3 running over the sides and tops thereof, which form concave depressions on the inner

walls of the box. On the inside, each corrugation has, at approximately the center thereof, an internal rib 8 having short tie ribs 9 extending from the main rib to the sides of the reinforcing corrugation 3, and the ribs 9 of one corrugation are connected to the ribs of the adjacent corrugation by means of additional transverse ribs 10.

1,561,041, Heat Treatment of Gears or the Like, John W. White, Detroit, Michigan, Assignor to General Motor Corporation, Detroit, Michigan, a Corporation of Delaware.

This patent describes an apparatus and process of quenching toothed gears in which the gears are confined in a chamber 22 by means of the

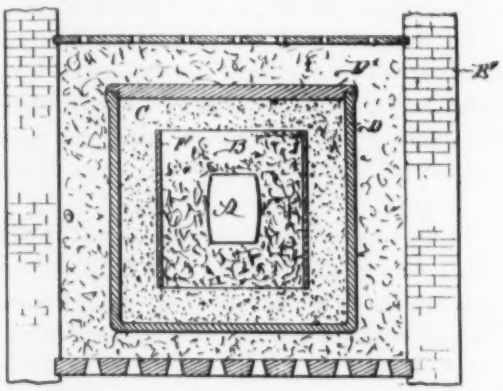


piston 36 and plunger in such a way that warping is prevented, and only the toothed portion is exposed, and while held in this position the toothed portions are subjected to the action of a measured quantity of quenching fluid from the tank 15, to impart the desired amount of cooling to only the toothed portion of the gear.

1,561,482, Carburizing Process, Nora E. Phillips, Chicago, Illinois.

This patent describes a carburizing process for cast iron, malleable or wrought iron, which comprises packing the article **A** to be treated in charred leather **B** and surrounding the charred leather packing with an outer layer **C** of bone-meal or other calcium bearing material, the whole being enclosed within a muffle **D** and heated in a suitable furnace E. For

complete carburization preparatory to hardening a cast iron bar one inch in thickness, the box should be kept in the furnace heated so as to maintain the metal **A** at a white heat for a period of approximately six hours, and then the article **A** is removed and immersed in a saturated solution

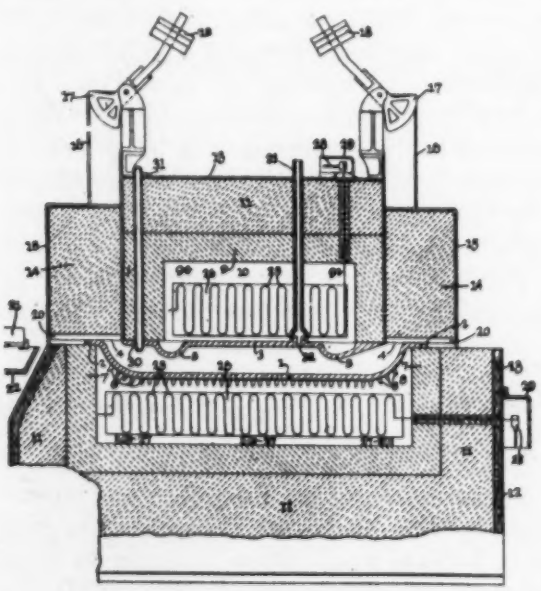


of salt water to cause the formation of a scale, which may later be removed in a sulphuric acid bath. The inventor states that gray cast iron treated in this manner is capable of receiving a temper and of being used for ordinary tool purposes, and is of such texture that a milling cut presents the appearance of a milled surface of a good quality steel.

1,561,577 **and 1,561,579, Quenching Device, Method and Apparatus for Heating Wire, Oscar C. Trautman, Lakewood, Ohio.**

These patents describe a furnace and quenching device for heat treating wires, rods and the like.

The furnace comprises the usual insulating outer casings and cover



11 and 14 having the inner chamber thereof heated by electric resistance

wires 25, 26. Inside the furnace chamber a closed semicylindrical pot 1 is supported in position to receive and pass out wires to be treated through the opening 20. The pot 1 is preferably provided with a plurality of prongs 6 projecting into the furnace chamber for more uniform heating. In the use of the apparatus the pot 1 is filled with lead, and the wires are passed slowly at the desired rate of speed through the lead bath. The depressions 5 in the top of the closed pot 1 insure the immersion of the wires in the material in the pot. Passing through the furnace, the wires emerging from the opening 20 are passed into the quenching bath of oil 21 which is maintained at approximately constant temperature and under continuous flow by means of suitably arranged inlet pipes or baffles, as described in the first numbered patent. Except for the entrance 20, the furnace is sealed to the atmosphere and the heat is entirely by radiation with a minimum of convection currents, so that uniformity in both the heat treating and the quenching bath is maintained.

INITIAL TEMPERATURE AND MASS EFFECTS IN QUENCHING

By H. J. French and O. Z. Klopsch

Continued from Page 74

above atmospheric temperature. However, this is immaterial as only the upper temperature ranges (cold water quenching) were considered in the comparisons of cooling velocity in this report.

Mr. Pillings comments regarding quenching in water at 50 degrees Cent. and the value of the exponent "n" in equation (7) as derived from his data are interesting but irrelevant. As stated in the report the described relations were developed for and applied only to coolants at atmospheric temperatures. An attempt to extend the scope of application to hot water is hardly justified. However, since this question has been raised by Mr. Pilling, a few comments will be in order.

While the authors have not yet studied mass effects when quenching into hot water in the neighborhood of 50 degrees Cent., they cannot accept Mr. Pilling's viewpoint that under such conditions the cooling velocity at 720 degrees Cent. is directly proportional to the surface per unit of volume (exponent n = 1) unless further evidence than that given in Mr. Pilling's discussion is presented.

In the authors' equation $V = \frac{(S)^n}{(W)} \times C_2$, the constant C_2 should be practically identical for the several specimens listed in Mr. Pilling's Table II if the proper value of n is applied and correct determinations have been obtained by Mr. Pilling of the cooling velocity at 720 degrees Cent., but this is in no case true. There is given in Table A below calculation of the constant C_2 for values of the exponent "n" equal respectively to 0.93, 1.0 and 1.2.

Table A.

Constants derived from data presented in Table II by Pilling

Stated Cylinder Diameter, Millimeters	Cooling Velocity at 720°C (720 x k as given in Table II)	Value of C_2 for various values of the exponent n (using $\frac{S_t}{W}$ in Table II)		
		n = 0.93	n = 1.0	n = 1.2
6.45	55.4	60.2	60.6	61.6
9.60	38.9	67.3	70.2	79.0
12.72	25.9	59.5	63.3	75.7
19.07	18.0	59.2	64.7	83.5

If the assigned value of n is too small, the constant C_2 will decrease with increase in diameter of cylinder and conversely if too large C_2 will increase. Now as indicated by Mr. Pilling, it is no easy task to determine quantitatively the cooling velocities in small masses of steel. In fact, the difficulties and sources of error multiply as the size of specimen becomes very small. Thus, if no very good agreement is obtained, the authors would first be inclined to disregard results on the smallest size. If in the table above, we neglect the cylinder 6.45 mm. in diameter, it would appear that Mr. Pilling's own data show the exponent n to be equal for hot water at 50 degrees Cent. to some value in the neighborhood of 1.2; it is only by neglecting the experiment on the larger cylinder 9.60 mm. in diameter that n can be taken at 0.93 as chosen by Mr. Pilling.

The main point raised is that insufficient data have been presented by Mr. Pilling to demonstrate that when quenching in water at 50 degrees Cent., the cooling velocity at 720 degrees Cent. is directly proportional to the surface per unit of volume.

DISCUSSION OF PREVIOUS PAPER AMPLIFIED

In order to clarify a portion of Mr. French's discussion of his paper entitled "Experiments with Nickel, Tantalum, Cobalt and Molybdenum in High Speed Steels," published in the December issue of TRANSACTIONS, page 681, Mr. French suggests the following data for the purpose of clarifying his reply to Dr. J. A. Mathews in the discussion on page 700: Added to the first paragraph of Mr. French's reply to Dr. Mathews at the top of page 700, the following table shows the exact analysis of molybdenum as determined by the authors.

Sample for analysis taken at depth below the surface as indicated (Inches)	Per Cent Molybdenum
1st cut 0.000–0.003	7.06
2nd cut 0.003–0.006	7.14
3rd cut 0.006–0.009	7.19
4th cut 0.009–0.012	7.15
5th cut 0.012–0.015	7.16
6th cut 0.015–0.018	7.16

News of the Chapters

STANDING OF THE CHAPTERS

IN the December issue of TRANSACTIONS appeared the relative membership standing of the 29 chapters of the Society as of October 1, 1925, and as of November 1, 1925. The tabulation which appears below shows the relative membership standing of the chapters on November 1, 1925, and December 1, 1925.

Standing as of December 1, 1925

GROUP I	GROUP II	GROUP III
1. Detroit (388)	1. Hartford (123)	1. Tri City (65)
2. Cleveland (377)	2. Lehigh Valley (107)	2. Los Angeles (62)
3. Pittsburgh (308)	3. Golden Gate (92)	3. Rochester (59)
4. Chicago (280)	4. Syracuse (88)	4. New Haven (55)
5. Philadelphia (264)	5. Milwaukee (87)	5. Worcester (52)
6. Boston (235)	6. Cincinnati (74)	6. Schenectady (51)
7. New York (222)	7. St. Louis	7. Rockford (50)
	8. Indianapolis	8. Washington (49)
	9. Buffalo	9. Toronto
	10. North West	10. Providence
		11. Springfield
		12. South Bend

Standing as of November 1, 1925

GROUP I	GROUP II	GROUP III
1. Detroit (388)	1. Hartford (123)	1. Tri City (65)
2. Cleveland (373)	2. Lehigh Valley (107)	2. Rochester (59)
3. Pittsburgh (307)	3. Golden Gate (93)	3. Los Angeles (59)
4. Chicago (276)	4. Syracuse (80)	4. New Haven (53)
5. Philadelphia (256)	5. Milwaukee (80)	5. Worcester (51)
6. Boston (223)	6. Cincinnati (75)	6. Schenectady (50)
7. New York (220)	7. St. Louis	7. Washington (50)
	8. Indianapolis	8. Rockford (48)
	9. Buffalo	9. Toronto
	10. North West	10. Providence
		11. Springfield
		12. South Bend

For the month of November there was a net gain of 58 new members, making a total net gain of 214 new members since September 1, 1925. This is a very commendable showing and we sincerely hope that this ratio of increase will be maintained.

Group I—Boston shows the largest gain of any chapter in this group, having acquired 12 new members. Philadelphia is second with 8, while Cleveland cut down the lead of Detroit from 15 on the last report to 11 on the present. We are not letting any secrets out of the bag but just a note of warning to the chapters of Group I—there is one chapter that has something up its sleeve that will begin to be evidenced next month, and it is a 2 to 1 proposition that there will be some radical rearrangements of these chapters soon.

Group II—Syracuse and Milwaukee were busy during the past month with a net gain of 8 and 7 each. They are now in a close contest for 4th position.

Group III—Rockford passed Washington for 7th position.

A summary of the standing of the Society since September 1, 1925, is given herewith:

	September 1	October 1	November 1	December 1
Members	2452	2508	2549	2585
Associates	500	523	538	541
Sustaining	243	243	245	256
Juniors	160	170	175	183
Honorary and Founder...	5	7	9	9
Total	3360	3451	3516	3574
Net Gain		91	65	58

BOSTON CHAPTER

THE Boston Chapter of the society was fortunate in receiving an invitation from Professor Albert Sauveur of Harvard University to attend a lecture presented by Francis F. Lucas of the Bell Telephone Company on Thursday, November 19.

Mr. Lucas spoke on the subject of "The High Power Photomicrography of Metals." Early in the lecture, he described the difference between the use of eye-pieces and objectives and the value of the numerical aperture; the magnification attained with white light and the recent development of ultra violet rays to increase the magnification. Color filters were also discussed. By the use of lantern slides, Mr. Lucas demonstrated what he called "empty magnification," or magnification without resolution, which gives a picture lacking in detail. He showed a series of slides which pointed out the effect of various objectives and filters on the same field and the difference between enlarging a photograph and magnification by the resolving power of an objective. Only by a careful study of the correct objective and eye-piece can the maximum resolution be obtained and "true magnification" result.

The talk was illustrated by a large number of exceptionally fine lantern slides of photomicrographs of iron and steel with varying magnifications up to 6000 diameters. These pictures showed careful preparation of

the specimens and remarkably clear resolution. A few of the slides were colored.

Members of the Boston Chapter were most gratified to have had this opportunity of hearing Mr. Lucas. *Frances Hurd Clark.*

In spite of the season's worst gale and rainstorm, more than one hundred members and guests of the Boston Chapter attended the December 4 meeting at the Massachusetts Institute of Technology to hear Professor Albert Sauveur deliver a talk on dendritic segregation.

Dr. Sauveur, who took as his subject—"The Directional Properties of Steel," explained in detail and showed with a series of diagrams and microscopic etchings the formation of the dendrite during solidification and cooling, its composition and methods of detection, using copper and other etching reagents. He showed that the physical properties of steel depend not only upon its microstructure, but also upon its persistent dendritic segregation or macrostructure, and that the latter is not effected by the usual commercial heat treatments, while hot working causes deformation of segregated areas and results in directional properties. In order to illustrate the effect of grain direction on static and dynamic tests, diagrams and etchings of broken tension and impact bars, taken parallel to and at right angles to the direction of work, were shown and figures given to show the relative strength and ductility of each. The much greater ductility and resistance to impact of the bars cut parallel to the direction of work was clearly seen.

Calling attention to the fact that when the steel ingot is subjected to hot working, a banded structure is necessarily produced and directional properties imparted which will be more pronounced the greater the reduction of the cross section, he felt we should abandon the belief that the more we work steel, the more we improve the physical properties. If the finished implement is to be subjected to transverse stresses, excessive reduction is very detrimental whenever persistent dendritic segregation exists.

In concluding his talk, Prof. Sauveur pointed out that of the two conditions on which the physical properties of steel depend, namely, its microstructure and its persistent dendritic segregation, or marcrostructure, the former has been the more widely studied, and made a plea for more study of the influence of the latter. One-half hour of discussion followed.

Previous to the meeting, dinner was served to seventy-five members of the chapter in the Walker Memorial, Professor Sauveur being the guest of honor. *H. E. Handy.*

BUFFALO CHAPTER

The November meeting of the Buffalo Chapter was held November 19, 1925.

The meeting was called to order by Mr. Armstrong. The minutes of previous meeting, October 22, were read and there were no objections.

Dr. Hartman of the Research Laboratories of the Carborundum Company, who was to be the speaker of the evening, was ill and could not be present.

Mr. Soley of the same company was introduced as the speaker for the evening.

Mr. Soley gave a short history of the manufacture of Carborundum, then gave in detail the present day manufacturing processes.

Five reels of pictures were shown which gave the manufacturing processes and the uses of the abrasive. An interesting discussion followed.

About forty members and guests were present.

The next meeting will be held December 17, and J. H. Nelson, of the Wyman-Gordon Company, is to be the speaker.

CHICAGO CHAPTER

For the sake of the analogy we will call them The Four Steelmen. Every day these four must work together and the result of their labors is fairly measured by the degree of co-operation they develop. They have come to recognize this fact and have taken advantage of it.

We have not always seen these Four Steelmen at the chapter meetings. Strange enough, the Shop Foreman was the first to identify himself with the organization but close on his heels came the Metallurgist. We do not know at just which relative time the Salesman put in his appearance; he was on the job from the beginning. For a time these three continued to meet every month at the chapter meetings, benefited by the interchange of ideas, formed new and useful acquaintances, gained a keener interest in and a higher regard for their vocations, and came to be loyal boosters of the society in general. However, of late we have noted with a great deal of satisfaction the arrival of the fourth member of the team. It was largely through the efforts of the Metallurgist that the Executive had the society forcibly called to his attention; at the same time he had not been ignorant of the increasing impression the organization was making in his business. Now in this case it so happens that the Executive has under his supervision the purchase of all the steel that enters into the product or the manufacture of it. The connection is perfect and all feel the effect of team work, whether it be good, bad, or indifferent.

We call this to your attention merely to give you a better background for our chapter gossip. You see, the society itself can thrive only so long as it continues to aid and abet the Four Steelmen. Well, the December meeting of our chapter certainly was an attractive one for all. The notices sent out carried the announcement that J. V. Emmons of the Cleveland Twist Drill Company would give a practical talk on high speed steel and that was sufficient to secure an excellent attendance. We counted 90 members and guests who came early for dinner at the City Club. After coffee was served the moving picture, Building a Skyscraper, featuring the 32 story Straus Building, was thrown on the screen and the attendants got a good idea of the precarious situations arising during the course of such an undertaking. Not many of us have made a flying jump for a swinging steel girder 30 stories up nor have we eaten our lunch with our feet dangling over the cornice from such a height that the cars below on Boul Mich look like two vibrating ribbons. By a trick of photography the structure was made to grow from the street level to the superstructure in two minutes whereas in reality it took 1800 men 18 months to complete the task. The two reels closed with the significant state-

ment that not one life was lost in the erection of this modern type of architecture.

By this time we were all set for Mr. Emmons and high speed steel. At the first Mr. Emmons outlined the classification and selection of the various types of high speed steel manufactured today. His discussion of the suitability of the different types for specific work was sufficient occasion for the executive who bought steel and the salesman who sold steel to get their heads together. Next, the speaker dwelled at considerable length on the matter of inspection. Here the metallurgist pricked up his ears and learned just how complete an inspection should and could be. A list of inspections included hardness (as received), depth of decarburization, segregation of carbides, dirt, surface laps and seams, chemical analysis, cutting ability, pipe, and after heat treatment, grain size and toughness. When Mr. Emmons came to methods of heat treating the steel, the shop foreman in charge of heat treatment was kept busy checking up and making mental notations. Safe to say that many suggestions gleaned at this meeting were put into effect the following day.

Mr. Emmons illustrated the microstructure of high speed steel by means of a number of excellent slides which were thrown on the screen. The meeting was closed at 10 o'clock sharp by the chairman in charge exercising his privilege of cutting short the discussion which followed Mr. Emmons' highly appreciated talk. *J. A. Comstock.*

CINCINNATI CHAPTER

Meeting: Friday, December 18, McMicken Hall, University of Cincinnati.

Subject: The Heat Treatment of Automobile Forgings—J. M. Watson, metallurgical engineer, Hupp Motor Car Corporation, Detroit.

To be reported in the next issue of TRANSACTIONS.

CLEVELAND CHAPTER

Meeting: Friday, December 18, Engineering Society Rooms, Hotel Winton, Cleveland.

Subject: General Precautions in the Manufacturing of Alloy Steels—M. A. Grossmann, United Alloy Steel Corporation, Canton, Ohio.

To be reported in the next issue of TRANSACTIONS.

DETROIT CHAPTER

The monthly meeting of the Detroit Chapter of the American Society for Steel Treating was held Monday, December 21, 1925, on the 15th floor of the General Motors Building.

The Detroit Chapter was honored by the presence of two National Officers, W. S. Bidle, president, and W. H. Eisenman, secretary. Both of these gentlemen gave short talks after dinner which kept the members in a roar of laughter. Before the papers were presented Mr. Bidle gave a short talk on the growth of the Society and causes for this growth, closing by thanking the chapter members for their support of him during the term of office. Mr. Eisenman gave an enthusiastic talk on self-salesmanship and the importance of the metallurgist to the plant.

The first paper of the evening was by H. A. Schwartz who spoke on

malleable iron from the viewpoint of the automotive industry. Mr. Schwartz, by the use of lantern slides, made a complete tour of malleable production. This survey of the malleable industry included occurrence of raw material, molding methods, casting, and annealing. Photomicrographs of the structure of white iron and malleable iron both good and bad practice, were shown. Examples of casting shrinkage and methods to overcome the trouble were illustrated. The effect of change of section was emphasized, and the mistakes often made by engineers who do not consider the characteristics of malleable iron were illustrated by diagrams of correct and incorrect design of automotive parts. A short discussion followed, mostly devoted to consideration of short annealing processes.

The second talk was by M. L. Frey of the Gerlinger Steel Foundry Company. The subject was "Heat Treatment of Cast Iron." Mr. Frey gave data on quenching soft iron to harden same, necessary temperature to remove casting strains and some results from using alloy pig iron in making semi steel castings.

F. P. Zimmerli.

GOLDEN GATE CHAPTER

A very successful "Smoker" was held on December 12 at the Engineers' Club, San Francisco, as the culmination of activities of the Golden Gate Chapter for 1925.

There were sixty-five present at the dinner, and this number was augmented by several members who came late.

F. B. Drake, the chairman, presided during the dinner, which was enlivened by music of Carl Anderson's Quartet as well as community singing led by Mr. Anderson.

During the meal there were a number of interruptions in the form of fictitious telephone calls for members present that caused much laughter.

The meeting was called to order at about 9:00 o'clock p. m. by Mr. Drake, who made a few brief remarks on the purpose of the gathering, which has become an annual affair. He then had a roll-call, which was followed by some remarks by C. S. Moody, the chairman of the committee which is handling the special course of metallurgy and heat treating. Mr. Moody announced that the organization meeting would be on January 11, at the Odd Fellows' Hall in Oakland, at 8:00 o'clock p. m., and that enrollment would be immediately followed by the first lecture. He also said that since it seemed there would be an unexpectedly large registration, plans had already been laid to have the laboratory and shop evenings in two sections, if necessary.

Carl Valledeo, heat treat foreman of the Hall-Scott Motor Car Co., then gave a short description of his visit at the Cleveland Convention this autumn. The Secretary followed with a few remarks on routine matters, including the statement that several qualified heat treaters and chemists were seeking positions.

The meeting was then turned over by Mr. Drake to S. R. Thurston, chairman of the "Smoker" Committee, who started the fun going by a very amusing talk on perfectly immaterial subjects. This introduction

was followed by a mock trial of one of our most highly respected members, conducted with all the nonsense to be expected on such occasions.

The remainder of the evening was devoted to humorous stunts of various kinds interspersed with some excellent music by our members, including S. W. Hilt, Mr. Harris and Mr. DeRoche, and several others.

Two exceedingly technical designs had been carefully drawn on blackboards as an interpretation of the iron-carbon diagram and other phenomena important to heat treatment, and they were now explained in detail by Mr. Eldridge.

The last serious event of the evening was a very thoughtful discussion by C. Gogle on the heat treatment of rubber tooth picks, and the meeting thereupon came to a close with some final songs.

All those present were not only pleased with a most enjoyable evening, but much gratified to realize what a large proportion of the evening's fun had been furnished by our own members' talent. *D. Hanson Grubb.*

HARTFORD CHAPTER

No report received.

INDIANAPOLIS CHAPTER

That the men in the industries in this district are deeply interested in increasing their knowledge of steel and its treatment was evidenced by over 130 members and guests who were present at a Special Duck dinner given by the Indianapolis chapter on Wednesday evening, December 9, at the Y. M. C. A. auditorium. Many unable to attend the dinner came in later to enjoy the musical program and the lecture of the evening, which was ably given by A. H. d'Arcambal, metallurgist, Pratt & Whitney Company, Hartford, Conn.

Because of the many special features on the program, little business was transacted, although time was given to William Chapin and Professor John Keller of the Purdue University to outline again the reasons for the "Steel Treaters" and the many advantages attendant with a membership in that Society.

Through the courtesy of The Merchants Heat and Light Co., of this city a special musical program was broadcasted over WFBM (268 meters) beginning promptly at 8:00 P. M. Intermingled with the musical program were short speeches by Mr. A. H. d'Arcambal on the "Why of Steel" and Mr. Homer McKee, President of The Homer McKee Advertising Agency of this city, who spoke on "Jerry Binder." Later Mr. d'Arcambal admitted that it was his first offense at talking steel to an invisible audience, although he had had the pleasure of "broadcasting" many times at various Chapter meetings in the past.

Even though urged by many of those present to prolong the musical program, which was well received, Mr. d'Arcambal was finally introduced at 8:55 P. M. and started the very interesting subject of "Manufacture and Heat Treatment of Small Tools," having with him an ample supply of samples which illustrated the special points he wanted to emphasize. Long discussions followed and continued after the meeting was adjourned until the time arrived when the "Y. M." had to sleep. In addition to the knowledge

which was imparted to those present, the local chapter was benefited by receiving numerous applications for membership. Nearly all of the near-by cities were well represented. *C. H. Beach.*

LEHIGH VALLEY CHAPTER

The December meeting of the Lehigh Valley Chapter was held Friday, December 4, 1925, at the Easton Public Library, Easton, Pennsylvania. The subject of "Photoelasticity and its Applications," was presented by Thomas H. Frost, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts. This subject is relatively new, and to date there has only been one description of the method before the American Society for Steel Treating; and that paper gave an application of the use to which it could be put in determining design. Mr. Frost gave a very complete description of the method, with various uses to which it is put, and illustrated these uses by typical examples. The response by an enthusiastic audience of about one hundred led to many questions which prolonged the meeting into almost a second lecture on the subject.

Photoelasticity is a method of measuring distribution of stress in a part by means of a method invented by Professor Coker of the College of London. A model of the part to be measured is made from specially prepared pyralin. The model is an exact reproduction of the part. It is placed in a specially designed machine and subjected to various intensities of stress. Polarized light is passed through the specimen, throwing an image of it upon a screen. When first stressed, this image will turn pink. Additional stress causes this color to pass through the spectrum to blue then white and the colors are again repeated. They are known in the order in which they appear, that is, red that is shown first is known as red of the first order, the second red as red of the second order, etc.

The colors remain uniform only as long as the distribution of stress in the specimen is uniform. As soon as this distribution becomes concentrated at particular points, these locations become highly colored and the colors shown are proportional to the concentration of stress. Roughly, red of the second order is twice the stress shown by red of the first order. Red of the third order is approximately 3 times the stress shown by red of the first order. This highly colored pattern shows clearly the distribution of stress in the material and can be mathematically determined by the following means.

A standard piece of pyralin is placed in a separate frame and stress applied. The specimen is superimposed at right angles to the stress which is to be determined upon the specimen under test, and the colored pattern examined. Additional stress is placed upon the standard test specimen until the unknown stress portions become black. The unit stress upon the standard test specimen required to produce this lack of color is equal to the stress in the specimen under test. The position of the test specimen at 90 or 180 degrees to the test specimen, determines whether the unknown stress is compression, or tension. These stresses can be

mathematically interpreted by careful examination with an accuracy of 2 per cent; but usually are determined only to an accuracy of 5 per cent.

It must be remembered that the method shows the distribution of stress and has nothing whatsoever to do with strain. For this reason it is permissible to use pyralin, glass or any other material which is isotropic and observe Hooke's law of proportionality between stress and strain. All determinations are carried out under the elastic limit of the material; otherwise, we obtain permanent colors. Strain is a deformation produced by stress, and stress is the unit force producing a deformation. By reference to the table giving modulus of elasticity of different materials we can determine the deformation which would be caused in them by the stresses determined by the photoelastic method. It should also be remembered that the mathematical formulas for the calculation of strength of materials do not, in any instance, confine themselves to a definite material such as steel, wood, etc. The beam formula and others apply whether the part is made from steel, wood or putty.

Mr. Frost gave many examples of the practical application of this method in solving problems which would otherwise be baffling. As for rapidity of determination over the usual method of "cut and try," he gave an illustration of a bridge which was being designed in France. Models of this bridge had been made, and at the end of two years, the designer had not yet solved the problem. A model was made and subjected to the photo-elastic test and in twenty days the factors which had prevented the completion of the design had been determined and corrections made. Mr. Frost also showed the model of a bridge, in which mathematically the members were supposed to be under tension. It was clearly seen on the colored photographs that one of the members was subjected to a considerable bending moment. The Ingersoll-Rand Company had become interested in this method and Mr. Frost showed several examples of the distribution of stress around fillets and how this was reduced by changing the shape of the fillet.

The meeting was very attractive to engineers, as well as to steel treaters, and really is an engineer's problem. The Lehigh Valley Chapter gathered members from several hundred miles for this talk and gave an illustration of how far it is possible to attract members to a meeting if an interesting subject is under discussion. Mr. Frost presented the subject very clearly and avoided the technical details which are often confusing to the layman. His illustration by means of many colored autochrome plates and a clear verbal description were such that everyone left the meeting with a satisfied feeling. This is the real test of a successful meeting and the Lehigh Valley Chapter can heartily recommend Mr. Frost to any other chapter who is desirous of pleasing the entire personnel of their membership.

H. V. Apgar.

LOS ANGELES CHAPTER

The December meeting of the Los Angeles Chapter of the American Society for Steel Treating was held in the club rooms of the Los Angeles

Creamery Plant the evening of December 2, 1925, and was "Part 2" of the November meeting.

On November 5, at 2 p. m., the members met at the plant of the Western Drop Forge Company, at which time George Moreland, manager of the plant and, incidentally, one of the Los Angeles Chapter charter members, had charge of the meeting and took the "Bunch" through his plant on an inspection tour. The members present had a rare treat, seeing a drop forge plant. All operations were witnessed, from the making of the dies to the finished product. Mr. Moreland's plant is the largest drop forge plant in the West, service and quality of product being the reason for the volume of business warranting a plant of such magnitude.

Mr. Moreland was speaker of the evening at the December 2nd meeting, and his subject "Drop Forging" was both interesting and instructive. He spoke briefly on the new 5000 pound board hammer now being installed in his plant. This hammer is the second one of its kind ever installed in this country, the first now being in use in the Chrysler automobile plant.

James Knapp told the members about what he saw of the Cleveland Convention.

Chairman Stiles sprang a good one on the members, "The Heat Treatment of Sam McGee," which proved to be a "knockout."

Robert Sangster, manager of the industrial department of the Los Angeles Chamber of Commerce, had a message for the chapter members which was very interesting. He gave statistics on the industrial situation in Southern California.

E. C. Black was called upon for his Hawaiian stunt, singing "My Honolulu Tom Boy" and "My Honolulu Hula Girl" with ukele accompaniment. (Much applause ensued).

The Steel Treaters' Trio rendered several good songs during the course of the meeting.

Forty members were present and all voted the meeting one of the best.

E. C. Black.

MILWAUKEE CHAPTER

Those of us who were fortunate enough to hear Prof. H. F. Moore of the University of Illinois give an illustrated lecture on "What happens when metal fails in fatigue" at the December meeting of the Milwaukee Chapter on the 14th were amply repaid for attending the meeting by the excellent manner in which the subject was handled.

Prof. Moore's great store of knowledge of the subject, derived from long experience and many exhaustive tests enabled him to deliver his lecture in a clear and concise manner.

Following the lecture there was a lively discussion on the theories advanced and showed the great interest the members took in the lecture.

There were 50 members at the dinner preceding the lecture and an attendance of 150 at the lecture.

N. F. Tisdale.

NEW HAVEN CHAPTER

No report received.

NEW YORK CHAPTER

"Round Table Discussion on Alloy Steels" was the subject of the November meeting of the New York Chapter of the American Society for Steel Treating. The customary get-together dinner preceding the meeting was held at Post Keller in the Woolworth Building. Following the dinner members and guests adjourned to the Merchants' Association Rooms, Woolworth Building where the meeting was held.

The New York Giants, otherwise known as Messrs. G. L. Norris, Vanadium Corp., C. McKnight, Jr., International Nickel Co., J. D. Cutter, Climax Molybdenum Co., C. E. MacQuigg, Electro Metallurgical Co., J. H. Hall, Taylor Wharton Steel Co., A. H. Kingsbury, Crucible Steel Co. of America, spoke on the special problems in manufacture and inspection of alloy steels—special properties which fit them for special services and special precautions in their working and heat treatment. The alloying elements discussed included vanadium, nickel, molybdenum, chromium, manganese and tungsten. The chairman, J. O. Rinek, in opening the meeting, stated that the rooters for the various alloys could yell themseves hoarse, but that no kicking or striking of opponents while down would be permitted. At the end of the contest when the score was tallied it was pleasing to note that few casualties had been experienced and the engagement had been one of sportsmanship and good fellowship.

The meeting was one of the best the New York Chapter has had. The papers were excellent, and it is only to be regretted that sufficient time was not available for a more thorough and complete discussion of each class of alloy steels. The outstanding features of the various papers on the alloy steels are as follows:

Vanadium Steels—G. L. Norris.

The speaker stated that there has been a 400 per cent increase in the amount of vanadium used in steel from 1909-1923. The discovery in 1905 of suitable vanadium ore in Peru furthered the use of vanadium in steels. The chemical combination in which vanadium exists in steel is due to its affinity for carbon appearing in the pearlite. Cementite containing vanadium tends to form sorbite, retards grain growth and segregation. The presence of vanadium in steel increases its resistance to wear and furthers its resistance to corrosion. Chromium-vanadium steel containing under 0.20 per cent vanadium is suitable for case carburizing purposes. The speaker stressed the value of vanadium in producing quality steels, the favorable response of vanadium treated steel to heat treatment and their better forgeability.

Nickel Alloy Steels—C. McKnight, Jr.

No special problems in melting nickel steel are experienced. Caution should be observed in using large percentages of nickel steel scrap high in chromium as a thick sticky slag may result. Nickel is not a curative agent and it has no value as a ladle addition to quiet steel. Blowholes and pipe do not weld up in rolling nickel steels, therefore, the use of hot tops is good practice. It is wise to strip the ingots while hot and roll at once. Nickel steel must be heated for rolling more carefully and to a higher temperature than carbon steels. In rolling nickel steel plates, the scale is much tighter than in the case

of carbon steels and great care must be taken to remove it; this is accomplished by using salt and wet burlap to blow off the scale. Seams and defects must be chipped out as in any first grade product. Flakes and woody structure encountered in nickel steels during the war cannot be blamed to nickel, but were a function of the way the steel was made. Intercrystalline cracks and sponginess are receiving a great deal of prominence at the present time. Nickel is no more blameworthy for this condition than for the cause of flakes, as a primary consideration is the method of handling after teeming. On the contrary, it is due to the restraining influence of nickel on segregation, the nickel steels are less susceptible than most to these troubles.

Nickel alloys with iron in all percentages, which accounts for the wide range of useful nickel-iron alloys. The speaker here noted the various iron-nickel alloys and cited their specific properties.

Per Cent Nickel	
0.25— 5	Structural
10—20	Not useful (Martensitic)
22—27	Corrosion resistant
24	Non-magnetic
24—32	Electrical Resistance
36	Invar
46	Platinite
50—80	Permalloy Alloys

In structural steels, nickel imparts toughness and strength; also fatigue and shock values may be emphasized with other alloys such as chromium (ratio 2½ to 1). Nickel steels, such as straight 3 and 5 per cent nickel and nickel-molybdenum are used for case carburizing purposes because of their response to heat treatment and the desirable characteristics obtainable. In forging, careful heating and common sense reductions will eliminate most troubles. Nickel steels are capable of being torch-welded, electric arc or resistance-welded, but will not hammer-weld. The machining difficulties are of condition and not of material. Investigation is being made and the results indicate that the speed, feed and shape of the tool must be accommodated to the material. Of these, speed seems to be the most important. Nickel lowers the critical range of steel, each 1 per cent lowering the range 20-24 degrees F. This reduces scale losses and warping. Also nickel has a definite effect on keeping the grain fine, so that temperatures that would ordinarily cause grain growth do not damage nickel steel and the steel can be held at the proper temperature for a long time without deterioration in grain growth. In fact, this is necessary as the sluggishness of the transformations in nickel steel require longer soaking at hardening temperatures. In heat treating nickel steel a normalizing treatment should precede other treatments. Normalized nickel steel castings give results comparable with good forgings, where before treatment they would be brittle and have less than 60 per cent of the strength of a forging.

Molybdenum Steels—J. D. Cutter

The speaker gave an historical outline of the use of molybdenum from the time of its isolation as an element by Hjelm in 1778 to the present day when

scarcely an automobile or truck can be found in which molybdenum is not incorporated. During pre-war years some considerable work was done by steel investigators with a view of determining the value of molybdenum as an alloying element in steel. The advent of high speed tool steel led to many efforts to employ molybdenum in quantaties greater than 1 per cent as a substitute for tungsten. These were never wholly successful and even to date no steel has been successfully marketed containing more than 1 per cent molybdenum. Although molybdenum does not make an entirely satisfactory high speed steel, still it does impart similar cutting qualities, and in view of the shortage of tungsten during the war offered the best available substitute. There is a supply of ore in Colorado far in excess of any demand that might be anticipated.

The form in which molybdenum is now added to electric and open hearth steel baths in the country is calcium molybdate ($CaMoO_4$). When this salt comes in contact with the molten bath, a remarkable reaction takes place based on the fact that iron has a greater affinity for molybdenum than oxygen has. The molybdenum is reduced to the metallic state and enters the steel in absolutely pure form, taking nothing with it, since all of the other components are slag forming elements (silica and lime) which furnish a practically neutral compound thus making possible the use of this form of addition agent in either acid or basic furnaces. Calcium molybdate contains no carbon or carbides, thus making it of even greater value as a toughener in steels.

Molybdenum forms carbides in steel which are hard and exceptionally resistant to wear. It also dissolves in the ferrite producing remarkable toughness. It has little effect on the ascending or Ac critical point, but produces a marked depression of the descending Ar point. It is a strong retarder of grain growth and exhibits a powerful tendency to retain carbides in solution on cooling. It apparently has a stabilizing effect on the ability to produce steels uniform as to "normality."

The physical properties of heat treated molybdenum steels which are most prominently brought out by comparative tests are high elastic limit and especially reduction of area in the tensile test, high impact value and great durability when subjected to abrasive wear. Likewise production tests prove that molybdenum steels "throw their scale" making clean forgings, have wide ranges in heat treatment, affording greater uniformity of product and above all show a degree of machinability which is truly remarkable and is a powerful influence in the rapid growth in the use of these steels.

Chromium Steels—C. E. MacQuigg

The speaker explained that he had been notified only a few hours in advance of the meeting that W. J. Priestly would be unable to be present, and he expressed Mr. Priestley's regrets.

In discussing the specific problems in manufacturing chromium alloys the speaker said that many of the ills and much of the grief which had been laid to the element chromium in chromium steels had been due in the past to faults in manufacture and that they were not necessarily due to inherent qualities of chromium steels. In the first place, it was necessary to make these steels as deoxidized steels and not as open steels. One reason for this was the great

refractoriness of chromium oxide. When it had once been formed in the steel it would be more difficult to clean up the steel than if the steel had been previously deoxidized. Moreover, if the bath was not shaped up previous to the addition of chromium, considerable chromuim losses might occur. Chromium steel was not a particularly difficult steel to make, but sloppy practice could not be indulged in or the results would be unsatisfactory. It is best to add chromium 20 to 25 minutes before tapping, and the reasons for uniform additions were discussed. As in the case of adding other alloys, questions of solubility had to be considered as well as questions of melting point. Casting temperatures were higher than for the same carbon content without chromium.

The best results were obtained by casting hot top ingots with the big end up for better yield. The necessity of stripping hot to avoid so-called snow flakes was mentioned as was also the reason which had been advanced to explain the differences of prevalence of snow flakes between electric and open hearth steel. Care is necessary in reheating chromium steel ingots to avoid cracking and billets should be slowly cooled to assist chipping.

In discussing the use of chromium steels the writer briefly outlined his own tabulation of these steels in which the various grades were correlated by chromium content and principal commercial use. This classification was briefly discussed with some outstanding feature in each group.

1. Engineering steels, such as combinations of chromium and other alloys for example, nickel, vanadium, molybdenum, etc., used largely in automobile construction. Chromium is contained in high speed steels up to around 4½ per cent.

2. The writer mentioned a type of chromium steel with 2½ to 3 per cent chromium and no other alloying elements which had been found to show very high shock resistance.

3. Rustless iron, stainless steel group with 12 to 15 per cent chromium. This group has prototypes of great commercial importance the usefulness of which is expanding very rapidly.

4. Alloys with 12 to 25 per cent chromium with other elements such as nickel which are exemplified in the Nichrome, Resistal, and similar types of alloys.

5. The higher chromium alloys, 20 to 35 per cent chromium, alone, for oxidation resistance. These are of increasing commercial importance and promise many useful applications among which was seamless tubing.

The precautions in heat treatment were briefly discussed in the remaining time, alloted the speaker.

Manganese Steel—J. H. Hall

Mr. Hall stated that manganese is unique because no steel can be made without it, since it is essential in order to counteract the red shortness due to sulphur. It is unique also because it is comparatively cheap. The erroneous findings of early chemists, that a manganese content of 1½-2 per cent makes brittle steel, were brought to the attention of the chapter. A manganese content of 1 per cent was said to be equivalent to 2 per cent of nickel in its effect on the physical properties of steel. Manganese, acting similarly to nickel, raises the tensible strength and elastic limit of steel very greatly without

decreasing the toughness. By holding the carbon content comparatively low, therefore, and raising the manganese, the strength can be brought to that of a much higher carbon steel, without the sacrifice of ductility. The deoxidizing power of manganese in high and low manganese steel was also cited. Steels containing 1.25-1.75 per cent manganese are used for rifle barrels, shaftings, forgings, rear axles, couple knuckles and for anchor chain of large ships. Mr. Hall called attention to the fact that steel under such conditions of use could not be brittle but must be able to endure heavy stresses and fatigues. A steel containing 0.50 per cent carbon and 2.5 per cent manganese was cited as having great possibilities for engineering service in the future. This steel, which has air hardening properties, can be made to give reduction of area and elongation of over 10 per cent, by suitable heat treatment. The special properties of high manganese steel (12 per cent manganese) in resisting abrasion accompanied by severe pressure or blows such as in switch points, frogs and crossings in steam and electric railway service, was also discussed.

Tungsten Steels—A. H. Kingsbury

Mr. Kingsbury stated that characteristics imparted to steel by tungsten do not make it suitable for structural purposes, but confine its use to tools and permanent magnet steels. The various tungsten steels were classified as follows:

Low tungsten, containing 1 to 1-¾ per cent of the alloy
Fast, Finishing, containing 2-¼ to 4 per cent of the alloy.
One or two brands containing as high as 7 per cent of the alloy.
Permanent Magnet containing about 5 per cent.

The beneficial effect of chromium and use in some cases of small percentages of vanadium in combination with tungsten for tool steels was discussed. The refinement of grain structure influenced by tungsten and the prevention of the formation of lamellar pearlite, as well as resisting the coagulation of proeutectoid cementite into the network formation is probably one of the best reasons why tungsten steels make superior cutting tools. The fact that Brinell, Scleroscope, Rockwell and file tests do not measure the variety of hardness best described as cutting hardness or durability of a cutting tool led the speaker to advance the following hypothesis:—

First—It must have a certain degree of hardness, dependent on the nature of the work it has to accomplish.

Second—The ability to retain this hardness at more or less elevated temperatures.

Third—The ability to resist heating or tearing away of the cutting edge. A possible designation for this third property is "cohesive strength."

The effect of tungsten in increasing the "cohesive strength" is the property which makes tungsten steels superior to other tool steels and permits higher cutting speeds. The necessity of raising the quenching temperatures when tungsten is used seems to be a decided advantage in permitting the proeutectoid cementite to be taken into solution, which in the case of plain carbon steels cannot be accomplishel without overheating, which results in weakness from coarse structure. Tungsten steels are sensitive to prolonged soaking at or near their proper quenching temperatures due to rapid growth

of grain with time. Thus, preheating, followed by a somewhat rapid heating to the quenching temperature is good practice. *W. E. Griffith.*

NORTHWEST CHAPTER

The December meeting, which was a joint meeting with the Minneapolis Section of the American Society of Mechanical Engineers, was held Tuesday, December 15, 1925. Professor Moore of the University of Illinois gave a talk on "What Happens When a Metal Fails in Fatigue."

Mr. Moore first discussed the correlation of the engineering view point of testing material with its metallographic structure. According to him the assumptions of engineers in making tests are:

1. The metal is homogeneous.
2. The material is isotropic.
3. Hooke's law holds.

If only small parts of metals are considered, these assumptions are not correct as the microscope shows that no metal is homogeneous, and from the experience of engineers the second and third do not hold rigidly; if, however, the areas of material tested are taken large enough the assumptions would be fairly accurate. This may be compared to the statistics applied by life insurance companies. If a large group is considered, such as for instance a city, it is possible for them to predict with a fair degree of accuracy how many deaths will occur within a certain time. If a smaller group is considered, such as a family, it would be more difficult to predict the deaths that would occur, while if just one individual is taken it would be impossible to predict the time of his death with any degree of accuracy.

The stresses that may be considered in a piece of steel are:

Internal forces
Elastic distortion
Distortion due to slipping.

The effect of slip in reversed bending was clearly illustrated by means of a pack of cards in which the separate cards indicated slip planes. If all the slip occurred in one direction the displacement of the metal would be large, but if parts of the metal would slip in one direction and other parts in the reverse direction, the displacement would be much smaller even though the amount of slip were the same. If we would consider slippage alone, there might be an increase in physical properties, but there is at the same time a tendency for rupture to occur. This was illustrated clearly by photomicrographs taken while the material was subjected to repeated stressing in which cracks were shown to develop along the slippage planes. The effect of pearlite grains on the path of rupture was well illustrated by a photomicrograph which showed that the path is diverted from its original course if it strikes one of these grains. The tendency to rupture will increase as the stress is applied and finally failure results.

This type of failure was first thought to be due to the fact that the steel crystallized, because the fracture always had a crystalline appearance. The microscope, however, disproved this as it showed that the metal was crystalline at all times. A better way to explain this failure would be to consider it as a progressive fracture. A small crack may have been present in the original

steel, or may have been started due to slippage bands caused by a concentration of the load at certain points. As the stressing continues the crack keeps on increasing and possibly other new ones are started. Finally the cross section of the material still holding becomes so small that abrupt failure occurs due to overloading.

Anything that would cause a concentration of load which would produce cracks should be avoided in the material. The causes most commonly met with, and which cause about 75 per cent of the progressive fractures, are rough machined surfaces, grooves, sharp shoulders, and sharp V-threads.

After the lecture there was a good discussion of fractured parts which members of the societies had brought along. The effect of fly wheels and bearings on shafts was shown to be similar to a notch effect or sharp corner due to increase in cross section causing a concentration of the load which would produce progressive fracture. This effect may be overcome by putting a shim between the fly wheel and the shaft or rounding the corners of the bearing surface of the wheel.

The societies were indeed fortunate to have Mr. Moore give such a clear, well-illustrated and interesting presentation of this subject. *L. J. Weber.*

PHILADELPHIA CHAPTER

The third regular meeting of the year was held on November 20, 1925, with a record attendance.

Two of the best papers yet presented to the Philadelphia Chapter were read. The first paper was read by E. E. Thum, of the Union Carbide and Carbon Research Laboratories, Inc., New York. Mr. Thum's paper covered a comprehensive discussion of the application of the oxy-acetylene flame to heat treating problems.

N. L. Mochel, metallurgical engineer of the Westinghouse Electric & Mfg. Co., presented the second paper and we believe it is the first one of its kind ever prepared. It deals with stainless iron from the consumers' point of view. The paper is replete with data covering the heat treatment and application of stainless iron to industry and it is the consensus of opinion of those who had the pleasure of listening to this paper that it is the finest treatise on stainless iron ever written. It is the earnest hope of the members of Philadelphia Chapter that this paper will appear in an early issue of TRANSACTIONS.

The members of Philadelphia Chapter wish to take this occasion to extend to everyone the Greetings of the Season. *A. E. Donovan.*

PITTSBURGH CHAPTER

The December meeting of the Pittsburgh Chapter was held on the evening of December 3 in the Bureau of Mines building.

A large number of members attended the supper in the cafeteria as the chapter had as guests W. S. Bidle, our president, W. H. Eisenman and J. E. Donnellan who spent a busy day in connection with the Recommended Practice Committee work as well as other society business. H. M. Boylston, the speaker of the meeting, was also a guest at supper.

Chairman O. B. McMillen called the meeting to order at 8 o'clock,

and the chapter was first addressed by Mr. Bidle who told of his visits to the various chapters since his election to office; and, in his opinion, what was needed to advance the interests of the society. In closing his talk he impressed upon his audience that they would get out of the society just what each, individually, would put into it.

Mr. Eisenman then followed with a talk on the metallurgist "selling" himself and his work to the manufacturing executive, and he told what plans were on foot to aid the society member to accomplish this.

Mr. Boylston was then introduced. He chose as his subject, "Some Experiments on Heat Treatment of Carbon Steel Castings."

He enumerated the A. S. T. M. recommended procedure of heat treatment for carbon steel castings. Then he gave specific examples of heat treatments which included annealing, and quenching in both water and oil with and without subsequent reheating. This was followed by a description of what physical properties might be expected from each treatment. He also warned against too high pouring temperatures which he said would cause large-grained castings. A number of references to similar work of other investigators was given during the talk.

Lantern slides of charts composed of physical test figures, both static and impact, were shown while the speaker explained their significance. These slides were followed by others showing the microstructures of the castings after various heat treatments.

At the conclusion of the talk, some questions were asked which aroused an interesting discussion. *H. A. Neeb, Jr.*

PROVIDENCE CHAPTER

No report received.

ROCHESTER CHAPTER

No report received.

ROCKFORD CHAPTER

The Rockford Chapter of the American Society for Steel Treating held its regular monthly meeting December 11. The usual "feed" preceded it, and everybody was feeling comfortable and receptive at 8 o'clock, when Mr. Hillman, the chairman, called the meeting to order.

After transacting the routine business the meeting was turned over to Mr. Muehlemeyer, chairman of the entertainment committee, who had the pleasure of presenting Mr. Knowlton of the Milwaukee Vocational School as speaker of the evening. Mr. Knowlton needed no introduction, as he is not a stranger in Rockford, and his paper on "Selection of Tool Steel and Some of Its Uses" was very closely followed by everybody.

Mr. Knowlton laid special emphasis on a few points such as: bearing in mind always the basic principles of the hardening of steel; using the right steel for a job to get best results; co-operation between the man who machines the steel and the hardening man, so that all the information possible is given to the hardener as to the name of the steel, its grade and temper, and the use for which the piece is intended; difference in meaning of "quality" and "carbon content" when applied to steel; and the need of close co-operation

between the user and the maker of the steel in order to obtain satisfactory results and maintain advancement in the art of steel treating.

The relative importance of chemical analysis was dealt with at great length. The speaker maintained that, while adhering too closely to the chemical analysis is possibly wrong, it is still good practice to hold to it reasonably closely.

The paper was exceedingly interesting because it was of such a practical nature that everybody recognized ideas similar to his own and was glad to hear someone else voice them.

After a friendly discussion of Mr. Knowlton's paper, Chairman Hillman announced that two attendance prizes would be awarded at the January meeting, one for the ladies and one for the men. The meeting was then adjourned.

R. M. Smith.

SCHENECTADY CHAPTER

Meeting: Tuesday, December 15, Twentieth Century Restaurant, Schenectady, N. Y.

Subject: Permanent Mold Aluminum Castings—J. B. Chaffe, Jr., The Permold Company.

No report of this meeting received.

SOUTH BEND CHAPTER

No report received.

SPRINGFIELD CHAPTER

No report received.

ST. LOUIS CHAPTER

The December meeting of the St. Louis Chapter was held at the American-Annex on the evening of the 11th.

The speaker of the evening was A. H. d'Arcambal, chief metallurgist of Pratt & Whitney Co., Hartford, Conn. Mr. d'Arcambal chose as the subject of his talk "The Manufacture and Heat Treatment of Small Tools."

The talk was well illustrated with lantern slides, and a remarkable collection of various tools and broken tools, which were of the greatest interest to the large and enthusiastic crowd that had assembled.

Proper steel, proper design, and correct heat treatment are three essentials of a good tool. Carbon, alloy and high speed steels each have their special places. The 18 per cent tungsten high speed steel is being used almost exclusively by the manufacturers, but for some heavy turning operations the low tungsten high vanadium type is superior; the latter, however, is a more sensitive steel and takes more care in its treatment.

Ground-thread taps and cutters were discussed and some of the records they have made were enumerated. The various designs of tools were illustrated by the samples that were exhibited. In high speed steel Mr. d'Arcambal believes that the carbon is as important as the tungsten and illustrated this by data he had obtained in practice. There is no short cut in drawing high speed steel; some tables of various tests showed clearly the advantage of the tools quenched and then drawn, over the tools

quenched in lead or salt at 1050 degrees Fahr. Mr. d'Arcambal believes large tool manufacturers should buy their steel on specification, but the general user will do best by buying his steel under brand names. Everyone voted this to be one of the best practical talks that they had ever heard. The meeting adjourned after the discussion which lasted until after 11 o'clock. *Alan Jackman.*

SYRACUSE CHAPTER

G. R. Brophy of the research laboratories of the General Electric Company addressed the Syracuse Chapter of the A. S. S. T. December 14, 1925, on the subject of "Stress Distribution in Railway Motor Pinion Gears as Determined by the Photoelastic Method." The talk brought to the attention of the members the possibilities for more exact determination of stress distribution in machine parts, which have hitherto been designed more or less by rule of thumb methods. In his particular problem, the speaker pointed out that the photoelastic method revealed that when pinions are subjected to an internal radial pressure such as they receive when they are shrunk and hammered on to motor shafts, a concentration of stress is found to exist at the base of the gear teeth rather than in the web between the teeth. By means of the photoelastic method, the investigators were able to account for failures occurring in practice and to alter the design to improve the part. The method is applicable not only to static stresses but also to stresses in moving parts.

Although the method has been known since 1816 and much work on the subject has recently been done by E. C. Coker of the University of London and Paul Heymans of Massachusetts Institute of Technology, in this country designers of machine parts have apparently not availed themselves of this tool.

It was brought out in the discussion that from time immemorial, when a tool or a steel part breaks in practice, the heat treater and steel manufacturer are the goats, although many failures may have been due to inadequate design for the load to which the part was subjected. *P. Peskowitz.*

TORONTO CHAPTER

No report received

TRI-CITY CHAPTER

Meeting: Thursday, December 17, Davenport Chamber of Commerce, Davenport, Ia.

Subject: What Happens When Metal Fails in Fatigue—Professor H. F. Moore, University of Illinois, Urbana, Ill.

No report of this meeting received.

WASHINGTON CHAPTER

Mr. Radclyffe Furness addressed the monthly meeting of the Washington Chapter on December 18th, his subject being "Steel Melting Practice." Mr. Furness' experience being confined to the basic open hearth, acid open hearth and basic electric processes, these were the only ones which he discussed. He described each as most suitable for production of some given class of articles and considered that none of the three processes was

the best for every use. His talk was further confined to steels made for rolling and forging of quality material and omitted from consideration such steels as are manufactured for structural shapes and plates. An outline was given of the desirable procedure in each of these processes and there are recorded below those features of each upon which he placed particular emphasis:

(a) *Basic Open Hearth:* Mr. Furness prefers to use under cold melting condition from 50 to 60 per cent of pig iron. It is extremely important that after melting-down sufficient carbon shall be present in the bath to be well above the proportion desired in the final product. The method of adding this carbon is not important in respect to the quality of the product but it has, however, a large bearing upon speed of operation of the furnace. Almost any variety of scrap (in respect to physical form) will do but extremely small material increases the charging time greatly. Mr. Furness has observed in basic operation a variation in manganese content of the bath at the completion of the heat, but before adding the final additions, up to as high as .75 per cent; the causes of this variation are not certain but ability to maintain large amounts of manganese throughout the operation would be beneficial to both quality and economy. Mr. Furness referred to stopping the oxidizing action of the slag toward the end of the heat by the use of blast furnace ferro-silicon.

(b) *Acid Open Hearth:* The importance of low sulphur and phosphorus scrap was emphasized. The physical character of the scrap was maintained as being of no importance whatsoever except in respect to its influence upon the time of melting, provided, of course, the desired carbon content at melt down is maintained. All steel scrap may be used in a charge but the operation will be excessively slow. A high silicon content on melt-down helps to provide heat on the addition of iron ore and hence the latter can be added more rapidly without chilling the bath. The reduction of silicon from the furnace walls and bottom at the end of the heat when "condition" is being reached, is responsible for the higher quality of acid open hearth steel as compared with that made in the basic open hearth. This is due entirely to the deoxidizing and degasifying effects of silicon, taking place an appreciable time in advance of tapping. Most of the alloying elements used are added after the addition of the silicon. The effect of too late an addition of nickel was given some attention.

(c) *Basic Electric:* This process owes its superiority to the second or final slag and its reducing and desulphurizing action. However, there is no "condition" as in the acid open hearth process and consequently it is not possible for the melter to determine by visual means the proper state of the bath nearly as well as in the acid open hearth process. Mr. Furness also considered that a disadvantage of the basic electric furnace was the fact that the circulation of the molten bath is poor and it is frequently possible to have the top surface of the metal thoroughly deoxidized and the bottom surface badly oxidized. However, there is much that can be done in the basic electric furnace that is absolutely impossible by the other processes, namely manufacture of such highly alloyed steels as high speed steel, stainless steel and the high tungsten tool and magnet steels.

Mr. Furness considered that more heats were spoiled after tapping, namely, in the actual production of the ingot, than were ever spoiled in melting, and made a plea for more care in ingot preparation. He remarked that it is difficult to tap a heat too hot from the open hearth furnace (although sometimes possible from the electric furnace), but it was readily possible to teem too hot and too fast. This condition resulted in extreme piping, and the opposite of pouring too cold or too slow or both, resulted in severe surface defects and entrapped non-metallic particles. His recommendation as to the best practice would be to tap as hot as is consistent with the avoidance of ladle and stopper troubles and to teem as cold and as slow as possible consistent with the avoidance of surface laps and the elimination of slag.

The discussion following this paper was extremely lively and extended over even a longer period than the reading of the paper itself. The subjects covered were the adjustment of pouring temperature and rate on the basis of the appearance of the metal as it rises in the mold, the use of a tun dish in pouring, the possibility of standardizing in any one shop the time and temperature relations of the tapping and teeming operations, and the details of the deoxidation process when using manganese, silicon, aluminum and other elements. *Jerome Strauss.*

WORCESTER CHAPTER

The regular monthly meeting of the Worcester Chapter was held jointly with the American Society of Mechanical Engineers and the American Institute of Electrical Engineers at the Hotel Warren, December 1. Fifty-three attended the luncheon served in the Winter Garden at 6:30 p. m.

The speaker of the evening was A. H. d'Arcambal, metallurgist for the Pratt and Whitney Company, Hartford, Conn., whose subject was the "Manufacture and Heat Treatment of Small Tools." The speaker had a large number of specimens and a collection of interesting slides to illustrate the points brought out during the talk.

Mr. d'Arcambal first featured this point. In order to make a satisfactory tool, three essentials are necessary, namely, the design of the tool itself; the highest grade steel of the proper analysis; and, the correct heat treatment. Since any deviation from these essentials results in unsatisfactory tool-life, the speaker described at length the methods employed by the Pratt and Whitney Company, to insure the necessary standards.

The inspection of steel not only includes chemical analysis and physical properties, but also microscopic examination to insure proper treatment at the steel mill; and macro-etching to guard against piped, segregated, and dirty material. Mr. d'Arcambal stated that a large user of high grade carbon and high speed tool steel should buy by analysis rather than by trade name. For the small user, however, without the proper laboratory facilities, the purchase of steel by trade name is the buyer's best guarantee of uniform quality. The control of carbon content in high speed steel is of utmost importance for satisfactory tool life. Pratt and Whitney's heat treating departments are ideally arranged and are equipped with electric lead pots, surface combustion, high speed furnaces and electric oil drawing furnaces. A constant pyrometer check and timing system is maintained to insure uniform results. *E. D. Clark.*

NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

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ROSE, JONATHAN, (M-8), heat treater, Crucible-Sanderson Works, Syracuse, N. Y.

RYAN, BERNARD J., (M-11), mill roller, Crucible Steel Co. of America; *mail* 124 Bryant Ave., Syracuse, N. Y.

SCHNEID, W. F., (M-11), rolling mill foreman, Crucible Steel Co. of America; *mail* 224 Whittier Ave., Syracuse, N. Y.

SCOTT, H. R., (M-12), production manager, Penna. Forge Co., Frankford, Philadelphia.

SEIFFERT, H. A., (M-1), foreman heat treating department, International Motor Co., New Brunswick, N. J.

SEWARD, JOHN N., (A-1), salesman, Crucible Steel Co. of America; *mail* Chattanooga, Tenn.

SHORTELL, WM. H., (S-12), factory manager, Millers Falls Co., West Haven, Conn.

SIEVERT, HANS. G., (A-12), vice-director, Aktiebolaget Max Sievert, Stockholm, Sweden.

SMITH, DR. F. M., (M-10), president, Church of Latter Day Saints; *mail* Box 255, Independence, Mo.

SMITH, OSCAR R., (M-11), chief chemist, W. B. Coleman & Co.; *mail* 450 Mulford Bldg., Fifteenth & Wallace Sts., Philadelphia.

STEELE, LEE B., (M-12), instrument maker, Naval Air Craft Factory, Philadelphia; *mail* 5814 Christian St., Philadelphia.

STEINMETZ, JOSEPH A., (S-10), president, American Resistor Corp., 917 Packard Bldg., Philadelphia.

STETLER, CHARLES E., (M-12), production manager, Light Mfg. Co.; *mail* 67 Edgewood St., Pottstown, Pa.

SVENSON, MARTIN O., (M-12), foreman hardening department, Winter Bros. Co., Wrentham, Mass.

SWENSON, C. R., (M-12), superintendent, The Oaks Co., Indianapolis.

TAMER, JOSHUA, (M-12), chief chemist, Crucible Steel Co. of America; *mail* 1671 Fifty-fifth St., Brooklyin, N. Y.

TAYLOR INSTRUMENT COMPANIES, (S-11), Rochester, N. Y.; attention: P. R. Jameson.

VANEK, FRANK J., (M-11), planer, Rock Island Arsenal; *mail* 904 Charlotte Ave., Davenport, Iowa.

WARD, WALTER F., (M-11), hammerman, Crucible Steel Co. of America; *mail* 215 Draper Ave., Solvay, N. Y.

WASHBURN WIRE CO., (S-12), Phillipsdale, R. I.

WATERHOUSE, J. B., (M-12), production manager, Nice Ball Bearing Co., Thirtieth St. & Nicetown Lane, Philadelphia.

WEICHERT, HENRY A., (M-11), superintendent, Subway Forge; *mail* 26 Favor St., Rochester, N. Y.

WELCH, CLAUD A., (M-6), 806 Gardenia Ave., Royal Oak, Mich.

WHIPPLE, A. D., (M-12), chief of laboratory, Trufast Laboratories; *mail* 5241 North Kimball Ave., Chicago.

YEATON, H. E., (M-12), night superintendent, Box 582, Pittsburg, Calif.

ZIEGLER, NICHOLAS A., (M-8), research laboratory, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.

Items of Interest

TO eliminate electrical contact troubles for all time, in connection with pyrometer recorders, the engineers of Charles Engelhard, Inc., 30 Church St., New York City, have developed a novel mercury contact switch which is unfailing in its operation. With this switch there can be no loose connections, and dirty contacts and corrosion are impossible.

The switch is simple in its design and it operates easily. It is simply a small glass tube containing mercury, a minute quantity of oil, and an inert gas. Platinum electrodes pass through the glass and are sealed. In position A the mercury makes contact with both of the electrodes, completing the circuit. To break the circuit the tube is tilted slightly to position B causing the mercury to flow away from the terminals to the other end of the tube.

The maximum angle of tilt required to make the mercury flow back and forth is only 15 degrees when operated with extreme slowness. When tilted quickly as in actual practice in the pyrometer recorder the angle is less.

The required number of mercury contacts are all mounted side by side within the recorder case, requiring but little space. For example, where six records are to be made on one chart simultaneously, as is possible with this type of recorder, six mercury contact switches are employed. In other words, a separate mercury switch is used for each circuit.

The manufacturers state that the slight additional cost of this trouble-proof switch makes its use well worth while.

The resistance is only 0.003 to 0.004 ohms, and never varies from these limits.

The low and constant resistance of these switches combined with their absolutely fume and dust proof features permit this recorder to be used in connection with electric resistance thermometers and thermocouples where extremely high precision is required and which would not be at all feasible with any other type of switch.

A. L. Feild has recently joined the metallurgical staff of the United Alloy Steel Corporation, Canton, Ohio. For a number of years Mr. Feild was on the technical staff of the Union Carbide & Carbon Corporation, first at the Cleveland works of the National Carbon Co., then at the Niagara Falls plant of the Electro Metallurgical Co., and then at the Union Carbide & Carbon Research Laboratories Inc., Long Island City.

After the first of the year, J. W. Bolton will be associated with the Frank Foundries Corporation, Moline, Ill., in the capacity of metallurgist. Mr. Bolton was formerly metallurgist at the Niles Tool Works, Hamilton,

Ohio, of the Niles-Bement-Pond Co. He has been doing research work for the Niles company for a number of years and has contributed to technical societies and to the technical press several articles on foundry subjects.

A Crabtree Memorial Fund is being founded by his former students in memory of the late Professor Frederick Crabtree, who at the time of his death on February 14, 1925, was head of the department of mining and metallurgical engineering at Carnegie Institute of Technology, according to an announcement from the institution.

The proceeds of the Memorial, it is announced, will be used to establish yearly mining and metallurgy scholarships which will be awarded to Carnegie students. The fund is being raised entirely through the activities of the alumni of the department of mining and metallurgical engineering and, according to the plans, the first scholarship will be awarded next year.

The trustees of the fund are C. R. Holzworth, '14, Youngstown, Ohio; A. D. Beeken, Jr., '14, Beaver, Pa.; A. W. Gittins, '08, Midland, Pa.; L. F. Reinartz, '09, Middletown, Ohio; E. B. Taggart, '10, Indiana, Pa.; and Professor F. F. McIntosh, acting head of the department of mining and metallurgical engineering.

Professor Crabtree died, after an extended period of illness, at St. Petersburg, Florida. He was born in Bramley, York, England, in 1867. He attended Massachusetts Institute of Technology where he was graduated with a B. S. degree in 1889 and later became professor of mining and metallurgy at Colorado College, Colorado Springs. In 1906, he joined the faculty at Carnegie and was a member of it until his death.

Tinius Olsen, founder and head of the Tinius Olsen Testing Machine Company, Philadelphia, celebrated his eightieth birthday December 7, 1925. A reception in his honor was held at the home of his son, T. Y. Olsen, at Mount Airy, Philadelphia, which was attended by a throng of friends, business associates and employees. Mr. Olsen is of international reputation, and has received many tributes in recognition of the service he has been, especially to his mother country. Among the gifts which Mr. Olsen received was a medallion in gold on which there was a splendid likeness of himself in relief. This was given to him by his employees, and their tribute showed the esteem in which he is held.

F. O. Hoagland, formerly of the Saco-Lowell shops, is now master mechanic in charge of engineering in the combined machinery and small tool departments of the Pratt & Whitney works, Hartford, Conn., of the Niles-Bement-Pond Co.

F. L. Lawrence, formerly connected with the Frost Gear and Forge Company of Jackson, Michigan, has accepted a position in the metallurgical department of the Pittsburgh Crucible Steel Company of Midland, Pa.

Leon W. Burns has recently accepted a position as assistant metallurgist, Remington Arms Co., UMC Bridgeport Works, Bridgeport, Conn.

The Danly Machine Specialties Inc., 4911 Lincoln Ave., Chicago, has recently issued a new catalog describing their die sets and die-makers' accessories. Preceding the catalog proper is a twelve-page section which gives a detailed description of the procedure in manufacturing die sets of the utmost precision under bulk production. This is a pictorial trip through the Danly plant. The catalog proper has the following table of contents: advantages of Danly devices; specifications and features of Danly devices; instructions for ordering; assembled die sets; advantages of die sets in the "knock down"; die sets in the "knock down"; steel punch shank; swivel adapter; leader pins; bushings; dowel pins; laps, pry bars; clamps; auto-gages; socket head cap screws; safety hollow set screws. It contains thirty-three pages. A copy of the booklet may be had upon request.

The HOMO Electric Drawing Furnace (patents pending), brought out recently by The Leeds & Northrup Company of 4901 Stenton Avenue, Philadelphia, Pa., is said to be a basic departure from previous practice in tempering steel parts in production quantities.

It is an electric furnace which heats by forced convection, rather than by radiation, and which uses air rather than oil or salt, as in the bath method, as the heating medium.

The principle advantages claimed for the Homo method are that uniformity is practically perfect, both as to time and temperature throughout the entire load, regardless of its density, that an accurate record of each batch is permanently recorded on a chart, and that subseqeuent batches can be made to match accurately, any previous one selected as standard. Operation is automatic and the time for bringing a load uniformly to temperature is so minimized as to greatly increase furnace output, thus reducing the number of units, the investment, floor space and fuel. Labor is reduced because the thoroughly insulated equipment can be placed directly in line of production and there is nothing to handle except the actual work, (no heating medium with its fire risk or fumes).

The furnace consists of a thoroughly insulated electric unit, perfectly adapted to a place directly in line of production, has an easily removable lid, and holds the work conveniently in a removable basket, two of which are used in connection with each furnace. One basket is unloaded and reloaded while the other is in the furnace.

Forced convection is applied as the heating means and air as the medium. Radiation has been practically eliminated as a means for transferring heat, since radiation (which strikes the parts nearest the heating elements and fails to reach those shielded parts in the center of the load) has been the greatest cause for uneveness in production drawing in the electric furnace.

To secure the needed uniformity of temperature, air is driven at a high velocity in alternate directions through the load and over the heating elements. The direction is reversed at short intervals alternately, this reversal being essential to the success of the method on which patents are now pending.

H. A. Baxter has been made manager of the steel sales department of

Henry Disston & Sons, Inc., Philadelphia, manufacturer of saws, tools and steel. He succeeds Charles T. Evans, retired. Mr. Baxter had been general manger of sales of the Tacony Steel Co. and the Penn Seaboard Steel Corp. at Philadelphia, for three years. Previously he was with the H. H. Franklin Automobile Co., Midvale Steel Co., and Tacony Ordnance Corp. He was a graduate of the University of Michigan and a member of many engineering and scientific societies.

The W. S. Rockwell Company of New York City has placed on the market a heat treating furnace (economizer shield type), with single or multiple chambers, openings at one or both ends. The advantages of this furnace are: comfortable working conditions; better heating conditions for the metal; flexibility in range of temperature, time and lead; accurate control of temperature and atmosphere; decreased cost of operation and maintenance; greater heat storage and slower cooling; lower cost of installation, with heavier construction. Several of these furnaces may be arranged for operation by one man, so that continuous production without automatic equipment is closely approached. The fuel used may be oil, gas or electricity. Designs are available for a great variety of requirements.

The Ford Motor Company has placed in operation at its River Rouge works a new 14-inch steel bar mill, installed by the Morgan Construction Company, Worcester, Mass. Test runs were made several days previous to being placed on production operation. The mill is the first completed of the series which will embrace everything from open-hearths to finished manufacture. It is housed in a brick, steel and glass structure 460x1600 feet with splendid concrete foundations and floors. Erection of the open-hearth department is going on at one end of this bar mill. The first open-hearth unit will include four furnaces, together with four electric furnaces. It is expected that these furnaces will be ready to operate next April.

Taylor Instrument Company has recently issued a catalog describing their Tycos Thermoelectric Pyrometers. The book gives the principle of operation of the pyrometer, tells where it may be used in different plants, and describes and illustrates some of the many kinds manufactured by the company. The catalog is attractively bound in paper, well illustrated, and gives much useful information regarding the Taylor product. It is 7½x10½ inches in size and contains 56 pages, including an alphabetical index on the last page. On the inside of the back cover is given a list of the available catalogs of Tycos instruments.

In a statement made public by the American Chemical Society Prof. J. R. Withrow, head of the department of chemical engineering, Ohio State University, Columbus, Ohio, compares tantalum with platinum and platinum-iridium in resistance to corrosion, and states that tantalum lasts 1600 times as long as platinum. Tantalum is one-twentieth cheaper than platinum. Prof. Withrow says that tantalum can be used as an engineering material, and has developed to be almost as valuable in corrosion resistance as platinum iridium, one of the best corrosion resistance alloys.

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EMPLOYMENT SERVICE BUREAU

POSITIONS WANTED

METALLURGIST AND CHEMIST with 14 years' experience in automotive industry, desires change. Past experience includes charge of both physical and chemical laboratories and heat treating departments. Also have had some foundry experience. Location unrestricted. Address 12-25.

FORGE SHOP FOREMAN, practical and competent, desires position. Has had 22 years' experience in all kinds of hammer forging, hardening, heat treating and tool maintenance. At present employed, and reasons for change are very good. Will furnish very good references. Address 12-15.

CHEMICAL ENGINEER desires position in the plant or laboratory. Three years' experience in the chemical, physical and micro laboratory on steel and nonferrous work. Address 12-30.

METALLURGIST CHEMIST with eight years' university and technical school training desires position. Experience covers three years in chemical and two years in financial field. Address 1-55.

METALLURGIST CHEMIST, aged 33, with 10 years' experience, desires to change position. Experience embraces blast furnaces, open hearths, electric furnaces, foundry, chemical analysis and physical testing, metallography and photomicrography of alloy steel, also of iron and steel castings. University graduate. Location unrestricted. Address 1-40.

CHEMICAL ENGINEER, university graduate, desires to change position. Has had 4 years' experience in the chemical analysis, physical testing, metallography and heat treatment of steel and nonferrous alloys. Address 1-60.

POSITIONS OPEN

WANTED: Hardener, primarily for hardening high speed steel. Steady work. Salary to start $140.00 per month. Answer stating qualifications and reference Pittsburgh district. Address 12-35.

WANTED: Experienced practical heat treater competent to handle entire department with capacity to heat treat upwards of 100 tons steel daily. Applicant must be experienced handling heavy work such as hammer dies, heavy alloy forgings, etc. Prefer practical man who is a student of metallurgy. State experience and education in detail, present and past positions, age, salary expected and references. Address 12-5.

WANTED: Alert, well-trained, energetic research worker, with good personality. Good general foundational training in metallography necessary, and several years' graduate, or equivalent work in an industrial laboratory, in nonferrous metallurgy, desirable. Salary commensurate with qualifications of applicant. Applicant please state qualifications fully and give references, age, nationality, religion, whether married or single, and salary desired. Address 1-20.

SALESMAN WANTED to sell ferromanganese to steel mills. Must have acquaintance with open hearth superintendents. Please state full particulars. Address 1-45.

WANTED—A Detroit representative on liberal salary plus commissions and expenses. Must be familiar with carburizing, and have a good following among heat treaters and metallurgists. Address 1-15.

Large company located in Connecticut has an opening for a HEAT TREATER who understands the present methods of tool hardening. An excellent opening for a good man. Address 1-30.

POSITIONS OPEN

WANTED: Experienced tool steel salesman. One who knows Michigan and Northern Ohio territories. Our mill is one of the oldest and manufactures a nationally known product. Excellent opportunities for the right man. Write stating age, experience and salary desired. Address 12-20.

WANTED: Man about 30, preferably married. Specialist in hardening of fine tool steels. Capable of taking charge. Able to meet people. Excellent opportunity for right man. Location about 100 miles west of Chicago. Address 1-35.

WANTED: Steel salesman—Man capable of developing mill shipment accounts; to represent steel mill specializing in tool and special steels. No warehouse. Territory Cleveland district, including Ohio. State training, experience and salary expected. Address 1-5.

Manufacturing concern has a splendid opening for a successful engineer who has had experience in selling industrial electric heating furnaces. State age, experience and education. Address 1-50.

FOR SALE

WANTED—A used Leitz Model M. M. microscope in first-class condition. Address 1-25.

FOR SALE—One 50 c. c. burette for calibration work and one 50 c. c. pipette for rough measurement. Both are in excellent condition, the burette being used for only 9 school-months and the pipette for about 3 years. About one pound of assorted rubber stoppers will be given away with these instruments. Will sell at whatever price you care to pay. The burette has the acceptable error of 0.03 per cent. Address 1-10.

FOR SALE—One Pittsburgh Instrument and Machine Company's Style "A1" Brinell testing machine in first-class condition. Address the Columbus Gear and Pump Co., 318-350 East Second Avenue, Columbus, Ohio.

FOR SALE: Exceptional Leeds & Northrup Furnaces. Guaranteed Brand New. Will sell at very great sacrifice. L & N "Hump" Heat Treating Furnace—1 No. 8058 Furnace, inside dimensions, 8½ inches in diameter and 22 inches deep. One No. 8551—F—S Recorder. L & N Drawing Furnace—1 No. 9262—24 furnace, inside dimensions, 12 inches in diameter and 24 inches deep. One No. 8970 Control Panel. One No. 8571—D—D—39 Controller. These furnaces were intended to through-harden automobile crankshafts made of ball-bearing steel which have been eliminated in the design and which has made the furnaces unnecessary. They were used only in a test, for a few hours. Address 12-10.

Chambersburg Board Drop Hammers for Immediate Disposal

Due to the increase in weight of our product, necessitating the installation of larger hammers, we have for immediate sale

1—1000 lb Chambersburg Board Drop Hammer, Serial No. 2428, installed new in 1915.
1—1400 lb Chambersburg Board Drop Hammer, Serial No. 2362, installed new in 1914.
1—1500 lb Chambersburg Board Drop Hammer, Serial No. 3367, installed new in 1918.

The hammers are in A-1 shape, are still on their foundations ready to operate and can be inspected at any time at our Coraopolis Plant.

To make room for other equipment, it is desired to dispose of these hammers quickly at bargain prices.

Pittsburgh Knife & Forge Company,
Coraopolis, Pa.

A 20-ton acid open-hearth furnace, built by the S. R. Smythe Co., and designed especially for making forging steels, was recently placed in operation at the Heppenstall Forge & Knife Co., Pittsburgh. The construction of this furnace was done in record time. Only five weeks elapsed between the time the furnace foundation was completed and the furnace was ready for drying out.

The Bureau of Standards has issued No. 513 of its series of Scientific Papers. The title of the paper is "Origin of Quenching Cracks," and the author is Howard Scott, physicist. The booklet contains 45 pages and is illustrated. It has a 3-page summary and a complete bibliography.

It is stated that the language of the Hittite Empire, which existed for about 10 centuries prior to 1200 B. C., has been deciphered by Dr. H. H. Bender, professor of Indo-Germanic philology at Princeton University. Among the tablets were found some relating to the working of iron mines in that period and the manufacturing of swords and chariots of iron. These were found in 1911 and 1912, but they defied the efforts of translators for years.

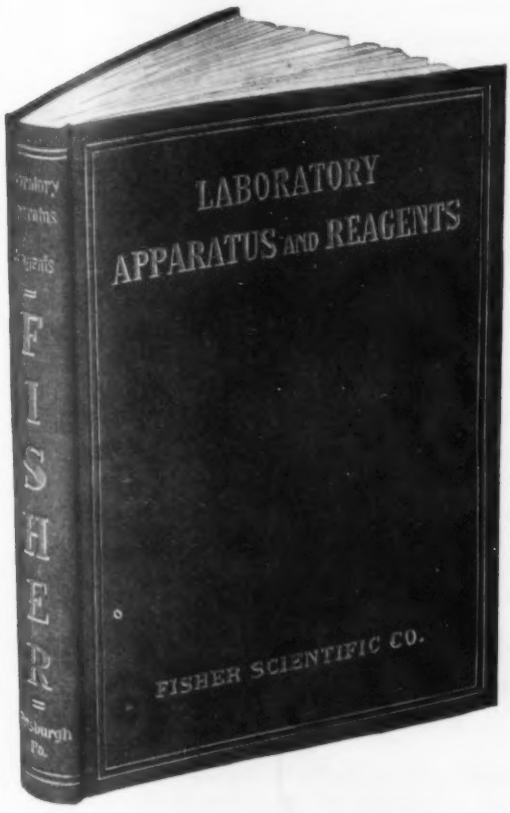
These tablets confirm other evidence that the Hittites introduced iron into general use. Their mines were on the north coast of Asia Minor. It is known that they gained military supremacy over Egypt for a time by their iron swords and their chariots. Iron was considered of such value at that time that it was used for gifts among the royalty.

One of the achievements at the Watertown Arsenal during the year 1925, stated in the report of Maj. Gen. C. C. Williams, chief of ordnance, War Department, is the development of the X-ray in the investigation of steel and other metals. The report states that this research work is "pioneer work of basic scientific character. It has already made good progress and is being continued to determine how far the basic research may be valuable in commercial and ordnance work."

"The X-ray has also been advantageously used in the examination of castings and other pieces of material to discover and locate defects not visible or otherwise discernable without destruction of the piece. Numerous projects have been carried out successfully by the Watertown Arsenal laboratories in connection with the investigation of strength of materials and their resistance to various effects."

F. V. Lindsey has been appointed sales manager of resistance-materials by the Driver-Harris Company. Mr. Lindsey has been identified with the manufacture of nickel and nickel alloys for a great many years, being vice-president and secretary of the Electrical Alloy Company previous to its purchase by Driver-Harris Company. It was under his supervision that the facilities of the Electrical Alloy Company were increased from a small wire drawing mill with limited production to one of the leading producers of nickel-chromium alloys for the electrical industry. His efforts will be concentrated in his new appointment on the manufacture and sale of

(Continued on Page 36 Adv. Sec.)



A NEW CATALOGUE

of

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LABORATORY APPARATUS AND REAGENTS

This Catalogue

—is different

—is more than a price list

—has been compiled to aid the man in the laboratory

Upon request, this catalogue will be sent without charge to Chemical and Metallurgical Laboratories

CHANGE OF NAME

The name of SCIENTIFIC MATERIALS CO. has been changed to

FISHER SCIENTIFIC COMPANY

The change was made to avoid confusion with the firms who have adopted names of a general character closely resembling our old name; also to denote the personal responsibility which has been back of this firm since 1902.

FISHER SCIENTIFIC COMPANY

LABORATORY SUPPLIES

PITTSBURGH, PA. U.S.A.

"Nichrome" for industrial and domestic applications, and the Driver-Harris Company feels confident that his wide knowledge of resistance materials will be of great benefit to the trade.

W. J. Nugent, vice-president and general manager of the Nugent Steel Castings Company, Chicago, was elected president to succeed Charles Piez at the meeting of the directors held in Chicago on October 27.

Prentiss Coonley was elected vice-president and C. A. MacDonald, secretary, was elected to fill a vacancy on the board of directors.

Mr. Nugent has been associated with the company since 1918, when the present plant was erected. From 1918 to 1921 he served as vice-president, and in 1921 became general manager as well. During this period the company enjoyed a steady growth, and it is announced that there will be no change in policy as a result of the recent changes in officials.

The interests of Mr. Piez have been taken over by Mr. Nugent and others. The company was organized in 1916 and has made electric steel castings since its inception. A large electric annealing furnace of recuperative type was recently installed and the entire output is now annealed in this furnace.

T. G. Straub has resigned his position as superintendent of the Evansville Tool Works, Evansville, Indiana, where he has been located for the past ten years. His present address is T. G. Straub, 534 Jefferson Ave., Evansville, Ind.

L. M. Griffith has resigned his position of engineer-in-charge of the Langley Memorial Aeronautical Laboratory at Langley Field, Va. After a short vacation he will be connected with the Famous Players-Lasky Corporation, West Coast or Lasky Studio, as mechanical engineer in charge of technical development and research work in their Hollywood laboratory. His address on and after January 1, 1926, is L. M. Griffith, Famous Players-Lasky Corp., Hollywood, Calif.

H. J. Barton, member of the Los Angeles Chapter of the A. S. S. T. has become affiliated with the Earle M. Jorgensen Company, distributors of steel and steel products, Washington Building, Los Angeles, in the capacity of sales manager.

In the annual report of the Bureau of Standards are stated many improvements in the technique of industry, with the benefits which these will bring to the general public. Industrial practice is improved, there is greater precision in commercial transactions, requirements for Government purchases are standardized, and discoveries have been made in the field of pure science.

Director G. K. Burgess states that during the year 171,196 tests have been completed, a 26 per cent increase over the preceding year. The sum of $43,202.86 was received for public tests. There has been a considerable increase in testing for Government establishments, and this line of activity is likely to increase, according to the report.

(Continued on Page 38 Adv. Sec.)

Permanent Magnet Steel

Composition is but one factor in the making of Permanent Magnet Steels. Thermal treatments before the steel goes to the customer are governing factors in obtaining proper values in finished magnets.

Simonds magnet steels are furnished in both Tungsten and Chromium grades in sheets, strips or bars. When required in the annealed condition, a special anneal is given, depending on the method of magnet manufacture. This anneal, while softening sufficiently to allow of cold working or blanking, is so regulated as to prevent loss of magnetic properties. Ordinary annealing will lower perceptibly these important values.

We maintain a magnetic testing laboratory for our own development work and to co-operate with our customers in helping them to produce a product of the highest quality. This service and our experience are available to those interested in producing high grade permanent magnets for meters, magnetos, radio work and the like.

We welcome the opportunity to improve your product, and to solve any of your present problems.

SIMONDS STEEL MILLS
LOCKPORT, N. Y.

SIMONDS

Thirty-five simplified practice recommendations have now been accepted, and many more are in process of acceptance, and surveys are in progress in many additional fields. The leaders in nine industries which have put simplified practice recommendations into effect estimate a saving of nearly $294,000,000 through this work.

An unusual combination of literary quality with technical and commercial appeal is given in a cloth-bound volume of 96 pages entitled "Firth-Sterling Tool Steels." The book states at the start that "Firth-Sterlingism is the doctrine of the human element in steel making and tool making, a just tribute to the man at the fire and the man at the machine." The subject matter is selected with reference to its application by the man with an engineering or metallurgical training and the man in the shop who is daily selecting, treating and using tool steels. The evolution of Blue Chip high-speed steel and of Firth-Sterling special tool and die steel at the company's mills at McKeesport, Pa., and the choice and treatment of the product by the user, are discussed. A dozen pages of the text are concerned with heat treatment, and here the importance of the personal element is emphasized. The book is effectively illustrated, and is exceptionally attractive and valuable. The manufacturing company and its agents, E. S. Jackman & Co., Chicago, deserve a great deal of credit for their work.

The Stanley P. Rockwell Company of Hartford, Connecticut, announce that as a result of the contest held at the Cleveland show the five tube Neutrodyne radio set has been awarded to Mr. Frank H. Kingdon, of the Sullivan Machinery Company, Claremont, N. H.

Mr. Kingdon's suggestion for a trade-name for the Rockwell Dilatometer was "VOLCRIT," which is quite suggestive of the operation of the equipment of indicating the exact time of quenching of the steel through determination of the critical points by the volume changes accompanying the transformations.

Many unique names were submitted and the task of selecting the winner was no easy one.

Each of the sixteen coal companies represented on the advisory board for the co-operative coal mining courses at Carnegie Institute of Technology has agreed to interest at least one prospective student among its employes to take either the two-year or the four-year degree course in coal mining next year, according to an announcement.

This action, it is pointed out, is to be taken in an effort to increase the supply of better-trained young men in coal mine engineering by increasing enrollment at Carnegie and by developing the institution's facilities to train larger groups of mining students each year.

Several of the coal companies, it is reported, are planning to help finance the student's expenses, either by loaning sufficient funds when he enrolls, or by paying, outright, at least half of the expenses. One of the companies will finance the second year for any of its employes who would

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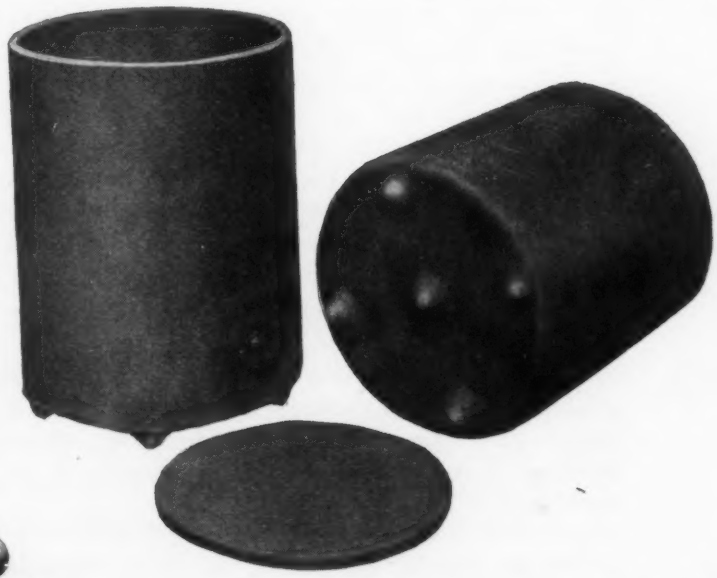
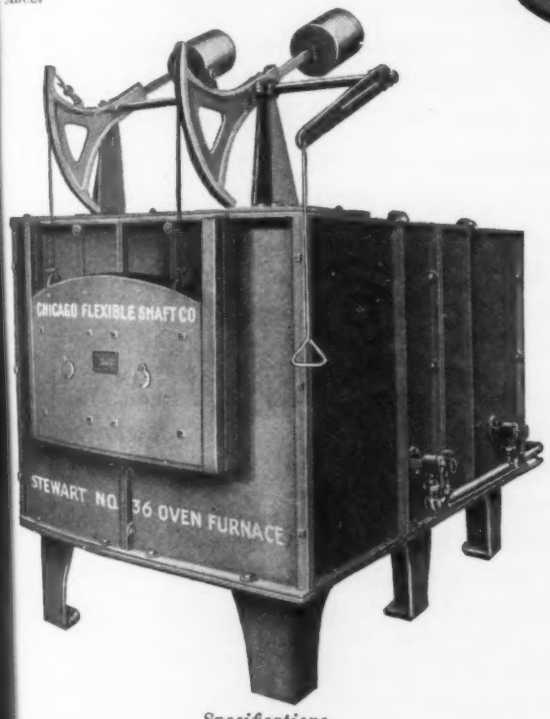
STEWART-POTS FOR CARBURIZING

STEWART Round Pressed Steel Carburizing Pots

STEWART Round Carburizing Pots are of pressed steel 5/16" thick with legs pressed in the bottom. They are seamless, one-piece steel containers, eliminating all chance of losing carburizing gases through sand holes, seams or welds. They reduce warpage to a minimum and afford even heat. Our large production enables us to quote unusually low prices; delivery from a large stock of assorted sizes.





Specifications

Opening	20 in. x 36 in.
Depth	72 in.
Floor space	68 in. x 94 in.
Gas connections	2 in.
Air connections	2 in.
Oil connections	½ in.
Requires	No. 6 Blower
Shipping weight	12,000 lbs.

STEWART No. 36 Oven Furnaces are in wide use for carburizing and annealing. They are big enough to receive and hold carburizing boxes and annealing pots of the larger sizes and to handle heavy and long work.

The Stewart Round Pressed Steel Carburizing Pots were designed especially to turn out work with an even case on all heats.

They save fuel, are more easily handled when loading and unloading the furnace. The resulting economy coupled with the high efficiency of Stewart Heat-Treating Furnaces make an ideal carburizing unit.

The Oven Furnaces are rugged in construction, lined with first quality bricks backed by the best quality of insulation and their reliability is known for many years in all plants where absolute uniformity in heat-treating is a necessity.

STEWART

Industrial Furnaces

CHICAGO FLEXIBLE SHAFT COMPANY

1144 S. CENTRAL AVE. - CHICAGO, ILL.

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Detroit, Mich.

4805 Park Ave
Indianapolis, Ind.

1200-1201 Standard Life Building
Pittsburgh, Pa.

943 Granite Bldg.
Rochester, N. Y.

608 Swetland Bldg.
Cleveland, Ohio

1738 19th Street
Milwaukee, Wis.

2024 Railway Ex. Bldg.
St. Louis, Mo.

Canadian Factory
349 Carlaw Ave., Toronto, Ont.

take the first year of the two-year course, and another has offered to finance any worthy employee wishing to take either a two-year or a four-year course at Carnegie Tech.

The coal companies represented on the advisory board of operators, labor officials, and engineers and which have joined in the agreement to interest at least one student each next year are the Hillman Coal and Coke Co., Vesta Coal Co., Greensburg-Connellsville Coal Co., W. R. Calverley, Inc., Westmoreland Coal Co., Pittsburgh Coal Co., Inland Colleries Co., H. C. Frick Coal Co., Bertha-Consumers Co., Bethlehem Mines Corp., Buckeye Coal Co., Republic Iron and Steel Co., Keystone Coal and Coke Co., Allegheny River Mining Co., Pittsburgh Terminal Coal Corp., and Ford Colleries Co.

The interest of these companies in increasing the enrollment of coal mining students at Carnegie is indicative of a shortage of properly trained junior executives in the coal industry, Carnegie officials point out, a shortage that the coal companies consider to be one of their most serious problems.

R. G. Atkins, member A. S. S. T., formerly in the metallurgical department of the United Alloy Steel Corp., Canton, Ohio, has accepted a position with the Latrobe Electric Steel Co., Latrobe, Pa., in the same capacity.

E. A. Hurme has been appointed manager of the electric furnace section of the industrial heating division of the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa. He was formerly manager of the steel mill section of the industrial sales organization.

O. T. Muehlemeyer, just appointed district manager for Illinois, Iowa and Wisconsin by the Rodman Chemical Co., Verona, Pa., formerly was metallurgist with the Barber-Colman Co., Rockford, Ill.

The Brown Instrument Company of Philadelphia has recently issued a new trade publication in the form of a ten-page pamphlet describing new designs of recording pyrometers. One of the advantages of these new designs is that of making more than one record, one instrument making six simultaneously. The designs are well illustrated.

Dr. J. A. Brinell, whose services in the field of metallurgy were recognized by metallurgists of all countries, died November 17. He had just been presented a medal in recognition of his services to the Swedish iron industry, the formal acknowledgment of which reached him just before the end came.

Dr. Brinell was a pioneer in the field of hardness testing and was the inventor of the ball type indentation testing machine which bears his name.